Linking Distress of Financial Institutions to Macrofinancial Shocks[*]

Alexander Al-Haschimi
European Central Bank

Stéphane Dées
European Central Bank

Filippo di Mauro
European Central Bank

Martina Jančoková
Goethe University, Frankfurt

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Abstract

This paper links granular data of financial institutions to global macroeconomic variables using an infinite-dimensional vector autoregressive (IVAR) model framework. The approach taken nests a global VAR (GVAR) model, which allows an assessment of the two-way links between the financial system and the macroeconomy, while accounting for heterogeneity among financial institutions and the role of international linkages in the transmission of shocks. The model is estimated using macroeconomic data for 21 countries and default probability estimates for 35 euro area financial institutions. This framework is used to assess the impact of foreign macroeconomic shocks on default risks of euro area financial firms. In addition, the macroeconomic impact of firm-specific shocks is investigated. Overall, the results show that accounting for heterogeneity among firms is important for investigating the transmisson of shocks through the financial system. The model also captures the important role of international linkages, showing that macroeconomic shocks scaled to those observed following the Lehman bankruptcy generate a rise in firm-level default probabilities that is close to those observed during this time period. By linking a firm-level framework to a global model, the IVAR approach provides promising avenues for developing macro-prudential tools that can explicitly model spillover effects among a potentially large group of firms, while accounting for the two-way linkages between the financial sector and the macroeconomy, which were key transmission channels during the recent financial crisis.

Keywords: Corporate sector credit risk, default probabilities, macro-prudential analysis, infinite-dimensional VARs, GVAR.

JEL Classification: C23, G33

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1 Introduction

In the wake of the financial crisis, financial supervisors re-evaluated the effectiveness of the macroprudential tools at their disposal. In hindsight, better models were needed to anticipate financial imbalances and to understand the impact of their unwinding on the real economy. Over the past years, research on macroprudential theory and practice has increased substantially.[1] One challenge, which is often encountered in the context of macro stress test exercises for financial institutions, is how to integrate a large number of key variables endogenously into a single, consistent model.[2] For instance, when linking firm-level distress indicators to the macroeconomy, not only is the domestic economy relevant but also the macrofinancial variables from key trading partners and global financial market hubs. That is, international macrofinancial linkages are both significant and complex. Second, heterogeneity among financial institutions and possible spillover of risks between firms are essential in accounting for the connectedness of the financial system. Finally, possible feedback effects from financial instability to macrodynamics are important, as negative feedback loops between the financial sector and the macroeconomic environment were among the key challenges to policymakers during the financial crisis. While these features of the relationship between firms and the macroeconomy are well-known, it remains a challenge to incorporate these into a single model framework, as doing so results in very large systems that are subject to the curse of dimensionality.

The contribution of this paper is to combine the infinite-dimensional vector autoregressive (IVAR) model framework, originally developed by Chudik and Pesaran (2011, 2013), with a global VAR model due to Pesaran, Schuermann and Weiner (2004) to relate granular data at the firm level to a high-dimensional set of international macro-financial variables. The resulting system yields a large-scale VAR in which all variables are endogenous, thereby enabling a finely detailed analysis of international linkages and spillovers between the macroeconomy and individual firms. Specifically, we apply the IVAR approach to the expected default probabilities of a set of euro area financial firms, where the default probabilities have been derived from credit risk models, and build a panel consisting of both firm-level risk indicators and a global set of macroeconomic variables. In contrast to other approaches, which first aggregate firm-level information at broad sectoral or country level before estimating two-way linkages with macroeconomic variables,[3] the IVAR approach estimates these relationships at the firm level, thus accounting for potential heterogeneity of the firms' macrofinancial linkages. As this framework nests a global VAR (GVAR) model, we also capture the international transmission of shocks to the euro area financial sector. Given that all variables are endogenous, we can further quantify spillover effects across firms. We consider two macroeconomic shocks in our framework, including a decline in U.S. equity prices and a negative shock to U.S. industrial production. For both shocks, we assess the impact on euro area macroeconomic variables and on the default probability of euro area financial institutions.

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[1] See, e.g., the workstream of the European System of Central Banks Macro-prudential Research (MaRs) Network.

[2] For reviews of macro stress testing models, see, e.g., Alfaro and Drehmann (2009), Drehmann (2009), and Foglia (2009).

[3] See, e.g., Chen et al. (2010).

The results show that when scaling the US equity shock to a magnitude observed following the Lehman bankruptcy, the model captures the rise in large firms' default probabilities on a scale similar to that observed during the Lehman episode. Furthermore, heterogeneity across euro area firms are found to be sizeable, thereby justifying an approach based on firm-level modelling. Finally, an adverse shock to a group of euro area globally systemically important financial institutions has the expected negative spillover to most other institutions in our model, while the impact on the macro environment is more limited but displays in most cases the expected sign.

The paper is organised as follows. Section 2 discusses the IVAR modelling approach and the link between firm-level and macroeconomic variables, and Section 3 describes the data used in the empirical application. Section 4 presents the specification of the model, its estimation and generalised impulse response functions for the analysis of U.S. and firm-specific shocks. Section 5 offers some concluding remarks and areas for future research.

2 The infinite-dimensional VAR approach

In constructing a high-dimensional VAR in which financial stress indicators from a potentially large set of firms are combined with a comprehensive set of international macroeconomic variables, the resulting parameter space is too large to enable direct estimation of the system. The IVAR framework introduced by Chudik and Pesaran (2011, 2013) offers an empirical approach that facilitates the estimation of VARs independent of the size of the system. The IVAR framework is closely related to that of the more well-known GVAR approach. The standard GVAR as presented, e.g., in Dées, di Mauro, Pesaran and Smith (2007) is motivated as an approximation to a global factor model that contains macrofinancial variables from a potentially large set of small open economies. The model allows for long-run relationships between the macrovariables, which are motivated by economic theory. Given the small open economy framework, the trade-weighted foreign variables are treated as weakly exogenous such that the system can be consistently estimated in country-by-country blocks.

The IVAR approach has many similarities to that of the GVAR, but it is more general in the sense that it starts with an arbitrarily large set of units and motivates the modelling strategy as an approximation to a large-scale system. In this system, there is no theory, a priori, how each unit is related to the remaining units. Rather, it is assumed that an individual unit has relatively strong links to a finite (and typically small) number of other, so-called 'neighbouring', units, while the individual links to all other units weaken as the number of variables in the system rises. That is, in the limit, the coefficients related to the 'non-neighbouring' units tend to zero as the total number of units N in the system tends to infinity. At the same time, even if the links to these individual units are not important, the non-neighbours can, in the aggregate, have a significant impact on an individual unit. This can be the case if there exists strong cross-section dependence across units in the system.

Chudik and Pesaran (2011) show that under a certain set of assumptions, such a high-dimensional VAR can be consistently estimated using unit-by-unit cross-section augmented regressions.[4] Here, the

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[4] See also Pesaran (2006).

large number of non-neighbouring units is replaced by their cross-section average (CSA). This CSA can be interpreted as an estimate of an unobserved common factor that captures strong cross section dependence. This approach greatly reduces the number of parameters to be estimated, while, similarly to the GVAR framework, the original large-scale VAR can be recovered from the unit-level regression estimates. In addition to the potential inclusion of 'neighbours', Chudik and Pesaran (2013) also explicitly introduce so-called dominant units to the analysis. This is a unit that has direct contemporary links to every other unit in the system. In the context of the GVAR, this could imply the separate inclusion of, e.g., US financial variables in the model of every other country, which is not typically done in the empirical applications of the GVAR.[5]

In our model framework, there are two different types of 'units'. One set consists of default probabilities for a set of 35 financial firms located in the euro area, denoted by the $M \times 1$ vector x_t. A second set of variables consists of macroeconomic time series for the euro area, collected in the $k \times 1$ vector y_t, and macro variables for 20 non-euro area economies, represented by the $(K-k) \times 1$ vector z_t. The aim is to estimate a high-dimensional VAR, where the firm-level and macrofinancial variables are all endogenous:

$$Q_0 \begin{bmatrix} z_t \\ y_t \\ x_t \end{bmatrix} = q_0 + q_d t + \sum_{l=1}^{p} Q_l \begin{bmatrix} z_{t-l} \\ y_{t-l} \\ x_{t-l} \end{bmatrix} + u_t. \tag{1}$$

In what follows, we will show how to use cross-section augmented regressions to estimate the high-dimensional system (1) in blocks. The structure of the sub-system in terms of z_t and y_t is very similar to that of a standard GVAR, and in this sense a GVAR is 'nested' in our model. In what follows, we provide the model structure for each sub-system of (1), starting with the firm-level variables in x_t.

2.1 Firm-level system

The firm-level model block for firm $i = 1, ..., M$ is estimated in first differences with the following specification:

$$\Delta x_{i,t} = \alpha_i + \sum_{m=1}^{p_{if}-1} \phi_{im} \Delta x_{i,t-m} + \sum_{l=0}^{q_{if}-1} \beta_{il} \Delta \bar{X}_{i,t-l} + \sum_{l=0}^{q_{im}-1} \delta_{il} \Delta \tilde{y}_{t-l} + \varepsilon_{i,t} \tag{2}$$

where $x_{i,t}$ denotes the financial stress indicator for firm i, $\bar{X}_{i,t}$ is the firm i-specific cross section average (CSA), and $\tilde{y}_t$ is a vector containing km variables of the k available euro area macro variables, with $km \leq k$. The CSA for firm i is defined as a simple average of all firms, excluding firm i:

$$\bar{X}_{i,t} \equiv \frac{1}{M-1} \sum_{j \neq i \in M}^{M} x_{j,t} \equiv s_i x_t \tag{3}$$

where s_i is a $1 \times M$ weighting vector, whose elements are given by $1/(M-1)$ and a weight of zero is placed on firm i, and x_t is a $M \times 1$ vector containing all firm-specific variables $x_{i,t}$.[6] The choice

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[5] See, e.g., di Mauro and Pesaran (2013) for a comprehensive summary of empirical applications of the GVAR.

[6] Note that in the current specification we do not include neighbours, which will be introduced in the next iteration of the paper. One challenge is that one could posit many strategies for selecting neighbours, including country of origin, relative

of equal weights follows the specification adopted in Chudik and Pesaran (2011). Asymptotically, the choice of weights should not affect the results; yet in practice, it has been shown that the weights used in finite samples can have a sizeable impact on the parameter estimates and impulse response functions (see e.g. Eickmeier and Ng, 2011). We combine the $M \times 1$ firm-specific weight vectors s_i into an $M \times M$ weight matrix s, such that

$$\begin{bmatrix} s_1 \\ \vdots \\ s_M \end{bmatrix} x_t = s\, x_t.$$

We can then stack the firm-level equations in (2) to obtain

$$\Delta x_t = \alpha + \sum_{m=1}^{p_f-1} \phi_m \Delta x_{t-m} + \sum_{l=0}^{q_f-1} \beta_l\, s\, \Delta x_{t-l} + \sum_{l=0}^{q_m-1} \delta_l \Delta \tilde{y}_{t-l} + \varepsilon_t, \tag{4}$$

where ϕ_m and β_l are $M \times M$ diagonal matrices, such that e.g.,

$$\phi_1 = \begin{bmatrix} \phi_{11} & 0 & \cdots & 0 \\ 0 & \phi_{12} & & \\ \vdots & & \ddots & \\ 0 & & & \phi_{1M} \end{bmatrix}.$$

Expressing (4) in levels, we obtain

$$x_t = \alpha + \sum_{m=1}^{p_f} \phi^m x_{t-m} + \sum_{l=0}^{q_f} \beta^m\, s\, x_{t-l} + \sum_{l=0}^{q_m} \delta^l\, \tilde{y}_{t-l} + \varepsilon_t. \tag{5}$$

where $\phi^1 = I + \phi_1$, $\phi^m = \phi_m - \phi_{(m-1)}$, and $\phi^{p_f} = -\phi_{p_f-1}$. To simplify notation, we write equation (5) as

$$\Xi\, x_t = A_0 + \sum_{m=1}^{\tilde{p}_f} A_m\, x_{t-m} + \sum_{l=0}^{q_m} \tilde{D}_l\, \tilde{y}_{t-l} + \varepsilon_t \tag{6}$$

where $\tilde{p}_f \equiv \max(p_f, q_f)$ and

$$\begin{aligned} \Xi &= [I - \beta_0\, s]\,;\ A_0 \equiv \alpha \\ A_1 &= I + \phi_1 + \beta_1 - \beta_0\, s;\ A_2 = -(\beta_1\, s + \phi_1)\,;\ A_m = \phi_m - \phi_{(m-1)} \text{ for } m = 3, ..., p_f - 1 \\ A_{p_f} &= -\phi_{pf-1};\ \tilde{D}_0 \equiv \delta_0;\ \tilde{D}_l = \delta_l - \delta_{(l-1)} \text{ for } l = 1, ..., q_m - 1;\ \tilde{D}_{qm} = -\delta_{q_m-1}. \end{aligned}$$

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size, bilateral exposures, etc., and there does not exist a consensus approach in the selection process. Therefore, we begin by estimating the system without neighbours, and will inspect the pairwise correlation of the residuals for evidence that after taking account of common factors, certain units may be subject to co-movements that have not been captured by the current model specification.

2.2 Euro area VARX*

The model for the euro area follows the VARX* framework of Pesaran, Shin and Smith (2000), which is also used in the standard GVAR model, except that the firms are allowed in the aggregate to have a direct impact on the macro economy, so as to capture the two-way feedback between the financial sector and the macrodynamics that was observed during the financial crisis. The VARX* for the euro area is specified as follows:

$$\begin{aligned} \Delta y_t &= \tilde{a}_0 + \tilde{d}t + \left[\begin{array}{ccc} \Pi_y & \Pi_{\bar{X}} & \Pi_{y^*} \end{array}\right] \left[\begin{array}{ccc} y'_{t-1} & \bar{X}_{t-1} & y^{*\prime}_{t-1} \end{array}\right]' \\ &\quad + \sum_{m=1}^{p_y-1} \tilde{b}_m \Delta y_{t-m} + \sum_{l=0}^{q_y-1} \tilde{\Psi}_l \Delta y^*_{t-l} + \sum_{l=0}^{q_y-1} \tilde{\Phi}_l \Delta \bar{X}_{t-l} + e_t \end{aligned} \tag{7}$$

where y_t is a $k \times 1$ vector of euro area macro variables, $\bar{X}_t$ is the cross section average of firm-level indicators, defined as $\bar{X}_t = s_y x_t$, where s_y is a $1 \times M$ weighting vector containing the elements $1/M$, and y_t^* is a $k^* \times 1$ vector of euro area-specific foreign variables, which are defined as trade weighted cross section averages of the non-euro area macroeconomic variables given by

$$y_t^* \equiv \tilde{w}_N \left[\begin{array}{c} z_t \\ y_t \end{array}\right].$$

Here $\tilde{w}_N$ is a $k^* \times K$ matrix holding bilateral trade weights between the euro area and the other countries in $\left[\begin{array}{cc} z_t\prime & y_t\prime \end{array}\right]'$.[7] Consistent with the VARX* framework in Pesaran et al. (2000), the contemporaneous foreign variables y_t^* are assumed to be weakly exogenous with respect to the long-run parameters in (7). In Section 4, we will test the validity of this assumption. The euro area macrovariables y_t and euro area-specific foreign variables y_t^* can be linked to the vector of all macroeconomic variables in the system using the relation

$$\left[\begin{array}{c} y_t \\ y_t^* \end{array}\right] = w_N \left[\begin{array}{c} z_t \\ y_t \end{array}\right],$$

where

$$w_N = \left[\begin{array}{c} \tilde{I}_N \\ \tilde{w}_N \end{array}\right]$$

with

$$\begin{aligned} \tilde{I}_N &= \left[\begin{array}{cc} \underset{k\times(K-k)}{0} & \underset{k\times k}{I} \end{array}\right] \\ \tilde{w}_N &= \left[\begin{array}{cc} \underset{k^*\times(K-k)}{\tilde{w}_N} & \underset{k^*\times k}{0} \end{array}\right]. \end{aligned}$$

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[7] For ease of notation, we assume that the euro area is ordered last among the countries $j = 1, ..., N$.

We can then write equation (7) in terms of z_t and y_t, given by

$$\begin{aligned}\Lambda_{0N}\, w_N \begin{bmatrix} z_t \\ y_t \end{bmatrix} &= a_{0N} + d_N t + \sum_{m=1}^{p_y - 1} \Lambda_{mN}\, w_N \begin{bmatrix} z_{t-m} \\ y_{t-m} \end{bmatrix} \\ &\quad + \sum_{l=0}^{q_y - 1} \Phi_l x_{t-l} + e_t, \end{aligned} \tag{8}$$

where the coefficient matrices are defined as

$$\begin{aligned} a_{0N} &\equiv \tilde{a}_0;\ d_N \equiv \tilde{d};\ \Lambda_{1N} = \begin{bmatrix} b_1 & -\Psi_0 \end{bmatrix}; \Lambda_{mN} = \begin{bmatrix} b_m & \Psi_m \end{bmatrix};\ \text{for } m = 1, ..., p_y \\ b_1 &= \left(I + \Pi_y + \tilde{b}_1\right);\ b_2 = \tilde{b}_2 - \tilde{b}_1; ...;\ b_{p_y+1} = -\tilde{b}_{p_y}; \\ \Psi_0 &\equiv \tilde{\Psi}_0;\ \Psi_1 = \left(\Pi_{y^*} + \Psi_1 - \tilde{\Psi}_0\right);\ \Psi_2 = \tilde{\Psi}_2 - \tilde{\Psi}_1; ...; \Psi_{q_y+1} = -\tilde{\Psi}_{q_y} \\ \Phi_0 &= \tilde{\Phi}_0 s_y; \Phi_1 = \left(\Pi_{\bar{X}} + \tilde{\Phi}_1 - \tilde{\Phi}_0\right) s_y; \Phi_2 = \left(\tilde{\Phi}_2 - \tilde{\Phi}_1\right); ...; \Phi_{q_e+1} = -\tilde{\Phi}_{q_y} s_y. \end{aligned}$$

2.3 Non-euro area VARX*

The specification for the non-euro area VARX* is closely related to the euro area counterpart in equation (7) except that non-euro area macroeconomic variables are not directly linked to euro area firms. In the empirical application, we will show that firms and international macro variables are still interlinked via the euro area variables. The VARX* for country $j = 1, ..., N-1$ is estimated in the following VECM form

$$\begin{aligned}\Delta y_{j,t} &= \tilde{a}_{0j} + \tilde{d}_j t + [\Pi_{yj}\, \Pi_{y^*j}] \left[y'_{j,t-1}\, y^{*\prime}_{j,t-1}\right]' + \sum_{m=1}^{p_j - 1} \tilde{b}_{mj} \Delta y_{j,t-m} \\ &\quad + \sum_{l=0}^{q_j - 1} \Psi_{lj} \Delta y^*_{j,t-l} + e_{j,t} \end{aligned} \tag{9}$$

where $y_{j,t}$ denotes the $k_j \times 1$ vector of country j's domestic macro variables, the $k^*_j \times 1$ vector $y^*_{j,t}$ represents country j's foreign variables, which are defined as trade weighted cross section averages of the non-domestic macroeconomic variables, given by

$$y^*_{j,t} \equiv \tilde{w}_j \begin{bmatrix} z_t \\ y_t \end{bmatrix}.$$

where $\tilde{w}_j$ is a $k^*_j \times K$ matrix holding bilateral trade weights between country j and the other countries in $\begin{bmatrix} z'_t & y'_t \end{bmatrix}'$. Similarly to the euro area VARX*, the country j-specific domestic and foreign variables $y_{j,t}$ and $y^*_{j,t}$ can be linked to all macroeconomic variables in the system using the relation

$$\begin{bmatrix} y_{j,t} \\ y^*_{j,t} \end{bmatrix} = w_j \begin{bmatrix} z_t \\ y_t \end{bmatrix} \tag{10}$$

where

$$\begin{aligned} w_j &= \begin{bmatrix} \tilde{I}_j \\ \tilde{w}_j \end{bmatrix} \\ \tilde{I}_j &= \begin{bmatrix} 0 & \cdots & 0 & I & 0 & \cdots & 0 \end{bmatrix}, \end{aligned}$$

where $\tilde{I}_j$ is a selection matrix picking out $y_{j,t}$ from z_t. Using (10), we can re-write equation (9) in levels as follows

$$\Lambda_{0j} w_j \begin{bmatrix} z_t \\ y_t \end{bmatrix} = a_{0j} + d_j t + \sum_{l=1}^{p_j} \Lambda_{lj} w_j \begin{bmatrix} z_{t-l} \\ y_{t-l} \end{bmatrix} + e_{j,t}, \tag{11}$$

where the coefficient matrices are similarly defined as for the euro area VARX* in (8).

2.4 Solving for the IVAR

We can now derive the initial large-scale VAR in (1) by combining the VARX*s for the non-euro area countries in (11) and for the euro area in (8) with the model block for the firm level equations in (6), to obtain

$$Q_0 \begin{bmatrix} z_t \\ y_t \\ x_t \end{bmatrix} = q_0 + q_d t + \sum_{l=1}^{p} Q_l \begin{bmatrix} z_{t-l} \\ y_{t-l} \\ x_{t-l} \end{bmatrix} + u_t,$$

where

$$\begin{aligned} q_0 &= \begin{bmatrix} a_0 \\ a_{N0} \\ A_0 \end{bmatrix}; q_d = \begin{bmatrix} \tilde{d} \\ d_N \\ 0 \end{bmatrix}; Q_0 = \begin{bmatrix} G_{zz} & G_{zy} & 0 \\ G_{yz} & G_{yy} & 0 \\ D_{g0} & -D_0 & \Xi \end{bmatrix} \\ Q_m &= \begin{bmatrix} F^m_{zz} & F^m_{zy} & 0 \\ F^m_{yz} & F^m_{yy} & \Phi_m \\ D_{gm} & D_m & A_m \end{bmatrix}; \text{ for } m = 1, ..., p; \\ u_t &= \begin{bmatrix} u_t \\ e_t \\ \varepsilon_t \end{bmatrix}, \end{aligned}$$

and where the G and F matrices are combinations of estimated parameters and the trade weights used to construct the foreign variables

$$G = \begin{pmatrix} \Lambda_{01} w_1 \\ \Lambda_{02} w_2 \\ \vdots \\ \Lambda_{0(N-1)} w_{N-1} \\ \Lambda_{0N} w_N \end{pmatrix}, \; F^m = \begin{pmatrix} \Lambda_{m1} w_1 \\ \Lambda_{m2} w_2 \\ \vdots \\ \Lambda_{m(N-1)} w_{N-1} \\ \Lambda_{mN} w_N \end{pmatrix}, \; m = 1, ..., p.$$

3 Data

In the empirical application, we use monthly data over the sample period June 1999 to September 2012. As regards the macroeconomic data, we include the following variables: industrial production $(ip_{i,t})$, the rate of inflation, $(\pi_{i,t} = p_{i,t} - p_{i,t-1})$, the real exchange rate $(e_{i,t} - p_{i,t})$ and, where available, real equity prices $(eq_{i,t})$, short- and long-term interest rates $(\rho^S_{i,t}, \rho^L_{i,t})$ and the oil price $(poil_t)$ for 21 countries (see Table 1). As in Dées et al. (2007), the macroeconomic variables are defined as follows:

$$\begin{aligned} &ip_{i,t} = \ln IP_{i,t},\ \ p_{i,t} = \ln(CPI_{i,t}), eq_{i,t} = \ln(EQ_{i,t}/CPI_{i,t}),\\ &e_{i,t} = \ln(E_{i,t}),\ \rho^S_{i,t} = (1/12) * \ln(1 + R^S_{i,t}/100),\ \rho^L_{i,t} = (1/12) * \ln(1 + R^L_{i,t}/100). \end{aligned} \tag{12}$$

The country-specific foreign variables $(ip^*_{i,t}, \pi^*_{i,t}, eq^*_{i,t}, \rho^{*S}_{i,t}, \rho^{*L}_{i,t})$ are constructed using fixed trade weights based on the period 2005-2007. The time series data for the euro area is constructed by cross section weighted averages of each variable for Germany, France, Italy, Spain, Netherlands, Belgium, Austria and Finland, using the average Purchasing Power Parity GDP weights over the period 2005-2007.

For the financial stress indicators of firms we employ 12-month ahead default probability measures obtained from the Kamakura Corporation. Kamakura (2011) estimates the firm-specific default probabilities using a Merton-type structural model, which measures financial distress with indicators on a given firm's market leverage as well as stock price volatility.[8] While the default probabilities (DP) are defined on the interval $[0, 1]$, we use a log-odds transformation given by

$$LOR_t = \ln\left(\frac{DP_t}{1 - DP_t}\right),$$

such that the log-odds ratio (LOR) is defined on the interval $(-\infty, \infty)$.[9]

We use default probability data for 35 euro area firms, which were chosen based on size of assets as well as data availability. As Table 2 shows, the 35 firms capture more than three quarters of all assets in the Kamakura database for financial firms in the eight countries that we use to approximate the euro area. Figure 1 shows the log-odds ratios for all 35 firms in our sample. The data show that the default probabilities of many firms peak towards the end of 2008, which corresponds to the period following the Lehman bankruptcy. At the same time, there is sizeable heterogeneity, with some firms experiencing stronger distress during the euro area sovereign tensions in early 2012, while other firms show high stress episodes in the early 2000s. Figure 2 shows the default probabilities for the largest five financial institutions, all of which are classified as globally systemically important institutions (G-SIFIs) by the Financial Stability Board, and which display a high degree of co-movement, suggesting that these large financial institutions react to a similar set of shocks.

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[8] Kamakura also uses other model approaches to estimate default frequencies, which relate a firm's default probability to firm- and industry-specific variables as well as macroeconomic time series. While this method provides a more accurate indicator of default risk by some measures, we do not use these as doing so would give rise to endogeneity problems when such an indicator is regressed on macroeconomic variables.

[9] While LOR_t is not defined for DP_t equal to 0 or 1, in practice a firm always has a positive default probability, and is in default before the probability estimated by Kamakura reaches 1.

4 Empirical results

4.1 Model specification and estimation

As detailed in Section 2, the IVAR model nests a GVAR model, similar to the one developed in Dées et al. (2007). In this paper, the global model covers 28 countries, where 8 of the 11 countries that originally joined the euro on 1 January 1999 are grouped together, and the remaining 20 countries are modelled individually (see Table 1). With the exception of the U.S. model, all models include the country-specific foreign variables, ip^*_{it}, π^*_{it}, eq^*_{it}, ρ^{*S}_{it}, ρ^{*L}_{it} and the log of oil prices (p^o_t), as weakly exogenous. In the case of the U.S. model, oil prices are included as an endogenous variable, with $e^*_{US,t} - p^*_{US,t}$, $ip^*_{US,t}$, and $\pi^*_{US,t}$ as weakly exogenous. As in Dées et al. (2007), the U.S.-specific foreign financial variables, $eq^*_{US,t}$, $\rho^{*S}_{US,t}$ and $\rho^{*L}_{US,t}$, are not included in the U.S. model, owing to the important role of the U.S. in global financial markets, such that weak exogeneity assumption does not hold for these variables. For the euro area, in addition to the country-specific foreign variables, the VARX* model also includes the cross-section average of the 35 default probability data ($CSA_{EA,t}$) as a weakly exogenous variable, thereby capturing the potential impact of financial firm distress on the macroeconomy. The firm-level IVAR model block expresses the default probability of firm j ($LOR_{j,t}$) as a function of the cross-section average across firms ($CSA_{i,t}$), euro area industrial production and euro area equity prices ($ip_{EA,t}$ and $eq_{EA,t}$). Overall, the system includes endogenous 152 variables. All variables are treated as I(1) processes, which was tested with the weighted symmetric Dickey-Fuller test, following Park and Fuller (1995).

For the non-euro area countries, the lag order of the individual VARX*(p_i, q_i) models, where p_i is the lag order of the domestic variables and q_i the lag order of the foreign variables, is selected according to the Akaike information criterion. Due to data limitations, we impose the restriction on the maximum lag to be 4 in levels. We then proceed with the cointegration analysis, where the country specific models are estimated subject to reduced rank restrictions. Table 3 gives the lag orders and the number of cointegrating relations for the 21 countries/regions. The final specification of the global model including the selection of the number of cointegration relationships is adjusted to ensure that the system is stable and that all long-run relations have well-behaved persistence profiles – see Figure 3 for key economies, the remaining persistence profiles converge at similar speeds – which indicates that the effects of shocks on the long run relations are only transitory (Pesaran and Shin, 1996). The trade weights for the foreign variables are shown in Table 4.

As a key assumption underlying the estimation strategy is the weak exogeneity of the foreign variables, we follow Dées et al. (2007) and provide in Table 5 the F-test statistic for the weak exogeneity test for all foreign variables, the oil price and, in the case of the euro area model block, the cross-section average of firm-level data. The weak exogeneity assumption is rejected for only 12 variables. Altogether, these rejections represent less than 10% of all the assumed weakly exogenous variables of the IVAR model. More importantly, the weak exogeneity of foreign variables, oil prices and the cross-section average of firm-level data (CSA_t) are not rejected in the euro area model. The same applies to the foreign variables ($y^*_{US}, \pi^*_{US}, e^*_{US} - p^*_{US}$) included in the U.S. model.

Turning to the estimation of the firm-level IVAR block, Table 6 presents the main results. The model is estimated in first differences and the lag order of the firm-level model is selected by the Bayesian information criterion individually for the autoregressive component, the cross section averages and the euro area macrovariables. Again, in some instances, the lag orders needed to be further constrained to ensure stability of the model. Contrary to the VARX* model block, we do not include cointegrating relationships in the firm-level model. The coefficients of ΔCSA_t are in all cases highly significant. Their value provides evidence that the default probability of a firm is linked to financial distress in the aggregate financial sector, confirming the existence of strong cross section dependence across firms. The coefficients of the macroeconomic variables do not always have the expected sign; however, few coefficients are statistically significant. The latter result may arise due to an identification problem as the cross section averages can be interpreted as proxies for unobserved common components across firms, while the macrovariables can be interpreted as observed common factors. To the extent that the observed and unobserved common components are correlated, the cross section average may capture effects of the observed common component as well (see also discussion in Chudik and Pesaran (2013) on the identification issue). The impulse response exercise will confirm that an adverse shock to US equities will have the expected sign in terms of the impact on the default probabilities of firms. Overall, the adjusted R^2 tends to be higher for large firms, with values up to 0.8 and tends to decline as the firm size becomes smaller, which may be due to the fact that smaller financial institutions may be subject to local shocks.

Finally, in Table 7 we examine the average pair-wise cross section correlations among the firms. The first and second columns confirm that there is a rather strong co-movement among the default probabilities of the firms, consistent with data shown in Figure 1. Importantly, when assessing the average pair-wise correlations of the residuals, we find that the cross-section average and the euro area variables together accounted for most of the co-movement in the data, such that the residuals are only weakly correlated across firms.

4.2 Generalised Impulse Response Functions

The large-scale VAR in (1) once estimated in its reduced form, can be used for impulse response analysis. This section presents two different types of simulations. First, we consider the impact of a negative shock to U.S. equity prices and a negative shock to U.S. industrial production on the default probabilities of firms. Second, we use the IVAR model to assess the impact of firm-level shocks on other firms and on the macroeconomy, thereby assessing the spillover effects across financial firms, and the two-way feedback from the financial sector to the real economy.

4.2.1 Negative shocks to U.S. equity prices and industrial production

The first set of results is related to U.S. variables so as to assess the international transmission of real and financial shocks. As the empirical application here is similar in spirit to macroeconomic stress tests on banks, we consider shocks of a size that correspond to tail events, which are more severe than the usual one-standard deviation shocks commonly used to demonstrate the dynamics of a model. Specifically, we calibrate the size of the shocks so as to replicate a decline in real and financial variables that are similar in size to what has been observed during the recent financial crisis. We first simulate a shock that leads to a decline by 20% in U.S. equity prices, which is close to the decline in stock prices observed following the Lehman bankruptcy. We then assess the impact of a drop by 4% in U.S. industrial production, which broadly corresponds to the magnitude of the decline in production after the Lehman event[10].

The 20% decline in U.S. equity prices has a strong spillover effect on the euro area economy (see Figure 4). Consistent with results in Dées et al. (2007), euro area equity prices decline by slightly more than its US counterparts, falling by 27%, while industrial production in the euro area declines by just over 2%. Importantly, the adverse financial shock in the US has sizeable spillover effects on euro area financial institutions. In response to the decline in equity prices, Figure 5 shows that the default probabilities (in log-odds transformation) rise by about 3.2 for G-SIFIs. When comparing this to the actual evolution of the default probabilities of the largest 5 institutions shown in Figure 2, this is very close in magnitude what was actually observed during the financial crisis.[11] Figure 6 shows the impact for all 35 firms in our sample, and can see that there exists relatively large heterogeneity in terms of responses across firms, which range between 1.2 and 3.8.

Turning to the adverse scenario on activity, a shock that leads to a peak decline of 4% in U.S. industrial production implies a decline of euro area industrial production of about 2% (Figure 7). Again, the default probabilities of the G-SIFIs all rise in response to the shock, with an average impact of about 1.3 (Figure 8), implying that a tail event sized real shock induces a smaller response than a tail-event sized financial shock. The extent of heterogeneity among firms remains, with responses ranging from 0.4 to 1.6 (Figure 9).[12]

4.2.2 The transmission of increases in the default risk of G-SIFIs in the euro area

One of the advantages of the IVAR modelling approach is to account for two-way feedback between the firm-level and the macro variables, as well as spillovers across firms. To illustrate this point, we simulate a one-standard deviation shock to the default probability of the G-SIFIs in our sample of firms (Figure 10). Figure 11 shows that a rise in the default probability to the G-SIFIs leads to increases in those of all other financial firms in the sample by around 0.4 on average, with the spillover to the average response being about 50% in terms of the size of the shock to the G-SIFIs. The extent of the spillover is again quite heterogenous, with the smallest effect being below 0.2, and the highest

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[10] Lehman Brothers filed for bankruptcy on 15 September 2008. In that month, U.S. industrial production declined by 4.2% and in October 2008 U.S. equities declined by 23%.

[11] Note that the relationship between a change in the log-odd ratio and expected default probabilities is state dependent. At the end of the sample period, the average default probability is about 0.6. At this starting level, the change in the LOR and the PD is approximately 1 for 1, such that a rise by 3.0 in the LOR corresponds to a rise in the expected default probability of about 3%. Again, this is close to what was observed during the peak of the financial crisis for the largest firms in our sample.

[12] Bootstrapped error bands for the impulse responses will be added in the next version of this paper.

exceeding a response of 0.7, which is close to the initial size of the shock to most G-SIFIs. Figure 12 shows that the shock to a single firm, together with its spillover impact to the remaining euro area financial sector also has an impact on the macroeconomy. As regards the impact on industrial production is rather limited, with euro area industrial production declining by about 0.1%. The impact on equity prices is somewhat more sizeable, with euro area equity prices declining by just over 2% after about three years. Overall, the results suggest that the model can capture a spillover effect from the financial to the real sector. When considering the limited decline in industrial production, one must recall that the one-standard deviation shock to the firms we simulate is far below the shock to default probabilities that we observed during the financial crisis.

5 Concluding Remarks

The macroprudential approach to financial supervision requires tools that provide quantitative assessments of the links between financial systems and the real economy, while accounting for spillovers and heterogeneity at the firm level. This paper shows that the IVAR modelling approach offers a way to capture the complex interactions between heterogenous agents. As the framework incorporates a large set of non-domestic macrovariables, it also accounts for the linkages between the firms and the global economy. This modelling approach therefore provides a flexible framework that can be adapted as a high-dimensional macro stress-testing tool. While the empirical application illustrated the performance of such a model, there is scope for further refinement, such as accounting for additional neighbourhood effects among firms, for example for those who specialise in similar areas or operate in geographically similar locations. As the IVAR can accomodate large set of time series, additional explanatory variable can easily be introduced at the firm level.

In addition, the paper also shows the importance of heterogeneity in the assessment of the transmission of shocks by including firm-specific information. Further research could deepen the understanding of the role of aggregation in such a model. One extension of the present analysis could relate to a comparison of the responses of aggregated sectors to macroeconomic shocks under two different estimation strategies; namely estimation based on firm-level information as in the present paper and that is aggregated ex-post, and an estimation at the sectoral level, where the firm-level data is aggregated ex-ante. Such a comparative analysis could illustrate the value added of the IVAR approach that accounts for both two-way feedback as well as potential heterogeneity among financial firms in macro stress testing models. Another avenue for future research pertains to the spillover between the financial and non-financial sector, where the firm-level block could be expanded to include non-financial firms. This extension could be used to model the extent to which distress in the financial sector spills over into other productive sectors of the economy.

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USA	**Euro Area**	**Rest of Asia**
China	Germany	Korea
Japan	France	Indonesia
UK	Italy	Philippines
	Spain	Malaysia
Latin America	Netherlands	Singapore
Brazil	Belgium	
Mexico	Austria	
	Finland	
Other developed economies	**Rest of Western Europe**	**Rest of the world**
Canada	Sweden	India
Australia	Switzerland	South Africa
New Zealand	Norway	Turkey

Table 1: Countries and regions in the IVAR model

Firm	**Country**	**Cumulated Assets (%)**	**G-SIFI**
1	DEU	10.23	x
2	FRA	19.56	x
3	ESP	25.65	x
4	FRA	31.64	x
5	NLD	37.48	x
6	ITA	42.13	x
7	FRA	45.62	
8	DEU	48.86	x
9	DEU	52.08	
10	ITA	55.29	
11	ESP	58.31	
12	FRA	61.01	
13	ITA	63.16	
14	NLD	64.89	
15	FRA	66.49	
16	BEL	67.78	
17	DEU	69.02	
18	FRA	70.14	
19	ITA	71.22	
20	AUT	72.26	
21	ESP	73.02	
22	DEU	73.58	
23	ESP	74.07	
24	ITA	74.46	
25	ITA	74.85	
26	ITA	75.14	
27	ESP	75.42	
28	ESP	75.69	
29	DEU	75.95	
30	ITA	76.20	
31	ITA	76.43	
32	FIN	76.65	
33	AUT	76.85	
34	ITA	77.04	
35	ITA	77.23	

Table 2: Summary of the financial institutions included in the model. The table presents for each firm the country of origin, the cumulative assets as a share of all euro area financial sector (as approximated by eight countries) assets contained in the Kamakura database. The final columns indicates whether the institution has been classified as a globally systemically important financial institution (G-SIFI) by the Financial Stability Board.

	Country names	**VARX*(p_i,q_i)**	**Rank**
1	USA	(2,1)	2
2	Australia	(4,2)	1
3	Brazil	(2,1)	2
4	Canada	(2,2)	2
5	China	(3,1)	1
6	India	(2,1)	3
7	Indonesia	(3,1)	2
8	Japan	(2,1)	3
9	Korea	(4,1)	3
10	Malaysia	(3,1)	3
11	Mexico	(1,1)	1
12	New Zealand	(3,2)	2
13	Norway	(2,1)	4
14	Philippines	(2,1)	2
15	Singapore	(2,1)	2
16	South Africa	(2,1)	1
17	Sweden	(2,1)	3
18	Switzerland	(4,2)	1
19	Turkey	(3,1)	2
20	United Kingdom	(1,1)	3
21	Euro Area	(2,1)	3

Table 3: Country model specifications.

Country	usa	arg	austlia	bra	can	china	india	indns	jap	kor	mal	mex	nzld	nor	phlp	sing	safrc	swe	switz	turk	uk	euro
USA	0	0.1483	0.1260	0.2416	0.7375	0.2293	0.1782	0.1079	0.2457	0.1736	0.1956	0.7187	0.1413	0.0683	0.2278	0.1504	0.1215	0.0858	0.0981	0.0848	0.1470	0.1904
ARGENTINA	0.0042	0	0.0013	0.1231	0.0009	0.0061	0.0062	0.0038	0.0014	0.0021	0.0035	0.0054	0.0008	0.0004	0.0039	0.0003	0.0129	0.0012	0.0014	0.0028	0.0014	0.0066
AUSTRALIA	0.0113	0.0051	0	0.0077	0.0044	0.0306	0.0427	0.0418	0.0474	0.0354	0.0336	0.0028	0.2532	0.0021	0.0152	0.0361	0.0282	0.0105	0.0062	0.0052	0.0120	0.0141
BRAZIL	0.0204	0.3429	0.0063	0	0.0061	0.0191	0.0137	0.0082	0.0097	0.0127	0.0054	0.0151	0.0036	0.0067	0.0043	0.0052	0.0205	0.0074	0.0076	0.0084	0.0075	0.0241
CANADA	0.2335	0.0095	0.0141	0.0212	0	0.0214	0.0161	0.0101	0.0223	0.0146	0.0069	0.0272	0.0185	0.0387	0.0071	0.0056	0.0238	0.0096	0.0120	0.0077	0.0218	0.0184
CHINA	0.1551	0.1235	0.1690	0.1062	0.0564	0	0.1482	0.1154	0.2461	0.2708	0.1244	0.0575	0.1092	0.0334	0.1143	0.1412	0.1021	0.0386	0.0276	0.0798	0.0536	0.1229
INDIA	0.0151	0.0191	0.0347	0.0163	0.0045	0.0243	0	0.0356	0.0099	0.0201	0.0287	0.0041	0.0092	0.0039	0.0077	0.0350	0.0280	0.0086	0.0087	0.0148	0.0157	0.0222
INDONESIA	0.0077	0.0091	0.0305	0.0076	0.0023	0.0179	0.0298	0	0.0375	0.0312	0.0415	0.0019	0.0247	0.0013	0.0210	0.1061	0.0076	0.0037	0.0017	0.0087	0.0034	0.0085
JAPAN	0.0903	0.0237	0.1749	0.0482	0.0318	0.1850	0.0456	0.1971	0	0.1737	0.1424	0.0372	0.1195	0.0186	0.2013	0.0935	0.1129	0.0236	0.0317	0.0268	0.0311	0.0562
KOREA	0.0345	0.0157	0.0663	0.0304	0.0112	0.1197	0.0468	0.0762	0.0890	0	0.0550	0.0235	0.0389	0.0106	0.0609	0.0541	0.0285	0.0099	0.0079	0.0294	0.0122	0.0280
MALAYSIA	0.0204	0.0124	0.0362	0.0115	0.0045	0.0337	0.0340	0.0603	0.0342	0.0275	0	0.0099	0.0277	0.0023	0.0626	0.1801	0.0131	0.0044	0.0027	0.0079	0.0074	0.0128
MEXICO	0.1419	0.0408	0.0067	0.0337	0.0268	0.0101	0.0086	0.0037	0.0135	0.0148	0.0050	0	0.0102	0.0012	0.0026	0.0041	0.0047	0.0039	0.0045	0.0033	0.0036	0.0158
NEW ZEALAND	0.0027	0.0006	0.0545	0.0005	0.0012	0.0027	0.0021	0.0055	0.0057	0.0038	0.0046	0.0010	0	0.0003	0.0051	0.0048	0.0025	0.0011	0.0010	0.0006	0.0026	0.0025
NORWAY	0.0043	0.0008	0.0016	0.0058	0.0105	0.0027	0.0034	0.0010	0.0030	0.0037	0.0008	0.0006	0.0017	0	0.0005	0.0025	0.0022	0.1163	0.0035	0.0056	0.0420	0.0360
PHILIPPINES	0.0075	0.0062	0.0064	0.0038	0.0017	0.0211	0.0034	0.0122	0.0201	0.0138	0.0231	0.0030	0.0119	0.0004	0	0.0287	0.0017	0.0009	0.0010	0.0014	0.0026	0.0047
SINGAPORE	0.0180	0.0026	0.0535	0.0130	0.0025	0.0357	0.0681	0.1814	0.0313	0.0350	0.1743	0.0054	0.0365	0.0072	0.1075	0	0.0123	0.0043	0.0075	0.0039	0.0157	0.0157
SOUTH AFRICA	0.0054	0.0154	0.0136	0.0117	0.0020	0.0092	0.0173	0.0048	0.0123	0.0068	0.0049	0.0003	0.0060	0.0016	0.0015	0.0034	0	0.0063	0.0061	0.0169	0.0162	0.0173
SWEDEN	0.0079	0.0056	0.0102	0.0101	0.0036	0.0062	0.0102	0.0055	0.0048	0.0044	0.0042	0.0023	0.0068	0.1118	0.0020	0.0031	0.0141	0	0.0112	0.0173	0.0251	0.0605
SWITZERLAND	0.0125	0.0109	0.0096	0.0151	0.0044	0.0065	0.0216	0.0035	0.0089	0.0048	0.0076	0.0029	0.0060	0.0078	0.0041	0.0081	0.0224	0.0124	0	0.0392	0.0217	0.0878
TURKEY	0.0048	0.0050	0.0030	0.0047	0.0015	0.0073	0.0096	0.0080	0.0032	0.0079	0.0034	0.0008	0.0024	0.0056	0.0012	0.0014	0.0087	0.0109	0.0101	0	0.0167	0.0409
UK	0.0435	0.0151	0.0503	0.0271	0.0275	0.0279	0.0591	0.0148	0.0261	0.0205	0.0207	0.0073	0.0448	0.2288	0.0114	0.0317	0.0880	0.0932	0.0552	0.0913	0	0.2146
EURO	0.1592	0.1877	0.1313	0.2605	0.0586	0.1836	0.2353	0.1033	0.1278	0.1228	0.1144	0.0732	0.1272	0.4490	0.1379	0.1046	0.3442	0.5475	0.6943	0.5441	0.5407	0

Table 4: Country weights (fixed weights based on the period 2005-2007)

Country	**F-test CV**	**ip***	**Dp***	**eq***	**ep***	**r***	**lr***	**poil**	**EA CSA**
USA	3.062	1.683	0.662		0.910				
Australia	3.943	0.111	0.039	0.211		2.499	0.001	0.076	
Brazil	3.063	3.247	5.614	1.716		0.148	0.836	1.870	
Canada	3.067	0.706	2.166	5.045		0.938	0.887	1.332	
China	3.916	1.281	0.015	0.039		3.849	2.111	0.024	
India	2.672	0.439	0.763	1.445		0.424	1.219	0.077	
Indonesia	3.068	0.571	7.859	3.037		0.070	2.068	0.109	
Japan	2.673	1.818	0.191	1.118		1.663	0.527	0.860	
Korea	2.698	0.354	5.126	1.351		1.192	0.588	0.436	
Malaysia	2.677	1.236	3.703	1.796		0.221	3.735	0.123	
Mexico	3.908	0.024	0.018	0.002		0.059	0.057	1.352	
New Zealand	3.074	2.048	0.276	0.084		1.646	0.599	0.382	
Norway	2.440	3.070	3.233	1.774		0.697	0.346	0.295	
Philippines	3.063	8.728	1.425	0.320		0.352	0.331	0.829	
Singapore	3.063	1.284	1.839	0.928		2.092	2.280	0.108	
South Africa	3.911	0.060	1.707	2.555		0.019	1.703	1.465	
Sweden	2.673	1.238	0.306	3.279		0.100	1.403	1.519	
Switzerland	3.943	0.249	7.876	0.078		0.009	0.037	0.454	
Turkey	3.068	0.172	2.151	0.355		2.417	0.571	0.215	
UK	2.670	0.577	2.754	0.730		0.815	0.992	0.185	
Euro area	2.674	2.191	2.296	1.964		1.182	0.280	0.987	0.605

Table 5: Test for weak exogeneity at the 5% significance level. The table displays the F-test critical value and the corresponding F-test statistic for all weakly exogenous (foreign) variables for all countries in model.

Firm	**constant**	$\Delta\mathbf{ar}_{t-1}$	$\Delta\mathbf{CSA}_t$	$\Delta\mathbf{ip}_t$	$\Delta\mathbf{eq}_t$	**VARX**$^*(p_{if}, q_{if}, q_{im})$	**adjusted R**^{2}
1	-0.0022	0.1741**	1.1187***	-1.4798	-0.5556	(3,2,1)	0.6878
2	-0.0001	0.2638***	1.0931***	-1.8441	-0.1431	(3,2,1)	0.6920
3	-0.0024	0.1648***	1.0490***	0.5396	-0.6746***	(3,1,1)	0.7834
4	-0.0036	0.0759*	1.1824***	1.7856*	-0.3662	(3,1,1)	0.7654
5	-0.0059	0.1293	1.5563***	-1.4394	-0.9065***	(3,3,1)	0.8074
6	-0.0002	NaN	1.4972***	1.7297	0.3416	(1,1,1)	0.7559
7	-0.0087	0.1063**	1.2200***	-0.0764	-0.7951**	(3,1,1)	0.7288
8	-0.0022	0.1662**	0.9309***	0.2037	-0.3061	(3,3,1)	0.5742
9	-0.0083	0.3940***	1.2119***	-1.0962	-0.6308**	(3,3,1)	0.7670
10	-0.0039	0.1910**	1.1562***	1.7162	-0.1079	(3,3,1)	0.6817
11	0.0016	0.1679***	1.0875***	0.3372	-0.3125	(3,1,1)	0.7477
12	0.0043	0.1557*	1.1247***	-0.1579	0.9806*	(3,3,1)	0.3457
13	-0.0018	-0.0301	0.9793***	-0.7950	0.0148	(3,1,1)	0.7110
14	-0.0042	0.2895***	1.1565***	-0.3899	-0.8935**	(3,3,1)	0.7121
15	0.0013	0.1160	0.5263***	-0.2949	0.2366	(3,1,1)	0.3079
16	0.0006	0.2661***	1.3234***	-0.7565	0.1837	(2,2,1)	0.6420
17	-0.0162	0.1727**	0.9842***	-1.2454	-0.7219**	(3,3,3)	0.6826
18	-0.0028	0.0195	0.4686***	-1.4762	0.0434	(3,1,1)	0.2060
19	0.0082	0.3766***	0.8521***	1.5522	0.6487**	(3,3,1)	0.5286
20	0.0007	0.1427***	0.9583***	-0.3279	0.2835	(3,1,1)	0.6466
21	0.0037	-0.0372	0.9661***	1.2820	0.3270	(3,1,1)	0.5334
22	-0.0133	0.0947	0.7332***	0.2592	-0.9663**	(3,1,1)	0.4917
23	0.0083	0.3325***	0.3996***	-0.2504	0.1370	(3,1,1)	0.2202
24	0.0195	0.1327*	0.7028***	0.1079	0.5132	(3,1,1)	0.2068
25	0.0025	0.0562	0.8934***	-1.1241	0.4767	(3,3,1)	0.3552
26	0.0112	-0.0205	0.6386***	1.0537	-0.0664	(3,1,1)	0.3362
27	0.0046	0.1552**	0.9363***	-0.5647	0.5594	(3,1,1)	0.4621
28	0.0026	0.0407	0.9729***	-0.0651	0.2111	(3,1,1)	0.4932
29	-0.0116	-0.0005	1.3165***	-0.1438	-0.2079	(3,1,1)	0.6316
30	0.0021	0.0718	0.9841***	1.2238	0.5985	(3,1,1)	0.3598
31	0.0036	0.1228*	0.6857***	2.5343**	0.3014	(3,1,1)	0.4481
32	-0.0039	-0.0582	0.7949***	1.1427	-0.1465	(3,1,1)	0.3127
33	-0.0010	0.2438***	0.5212***	0.1025	-0.0824	(3,1,1)	0.2603
34	-0.0030	0.0708	0.3762***	0.7848	-0.7665	(3,1,1)	0.0972
35	0.0061	0.0772	0.6450***	2.1237	-0.4336	(3,1,1)	0.2492

Table 6: Estimation results for the IVAR block.

Firm	**Levels**	**First diff.**	**Residuals**
1	0.74	0.58	-0.01
2	0.77	0.58	0.00
3	0.73	0.62	0.00
4	0.77	0.61	0.00
5	0.73	0.63	-0.01
6	0.77	0.62	-0.03
7	0.71	0.60	0.00
8	0.71	0.51	-0.03
9	0.60	0.59	-0.01
10	0.74	0.58	-0.02
11	0.74	0.61	0.00
12	0.58	0.40	-0.04
13	0.70	0.60	0.00
14	0.69	0.58	-0.01
15	0.61	0.40	-0.03
16	0.73	0.56	-0.02
17	0.51	0.56	-0.02
18	0.44	0.34	-0.03
19	0.68	0.47	-0.03
20	0.70	0.55	-0.03
21	0.73	0.53	-0.01
22	0.50	0.49	-0.02
23	0.64	0.29	-0.03
24	0.56	0.32	-0.04
25	0.65	0.44	-0.03
26	0.61	0.43	-0.03
27	0.63	0.48	-0.02
28	0.64	0.51	-0.02
29	0.58	0.56	-0.01
30	0.67	0.44	-0.04
31	0.66	0.47	-0.04
32	0.68	0.41	-0.05
33	0.50	0.35	-0.04
34	0.49	0.24	-0.06
35	0.65	0.37	-0.05

Table 7: Average pair-wise cross section correlations across firms.

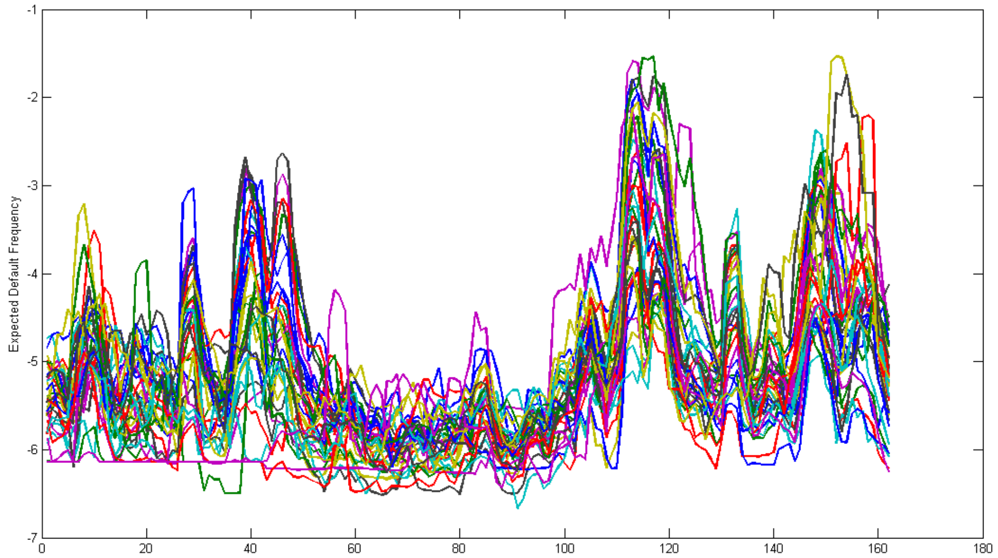

Figure 1: Default probabilities (in log-odd ratio transformation) for all 35 firms in the sample.

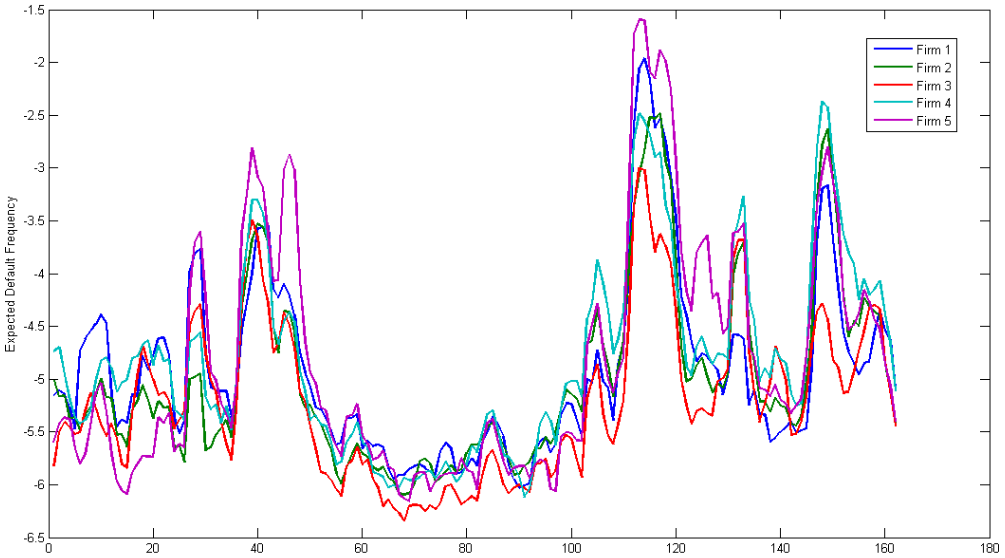

Figure 2: Default probabilities (in log-odd ratio transformation) for the largest five firms by assets.

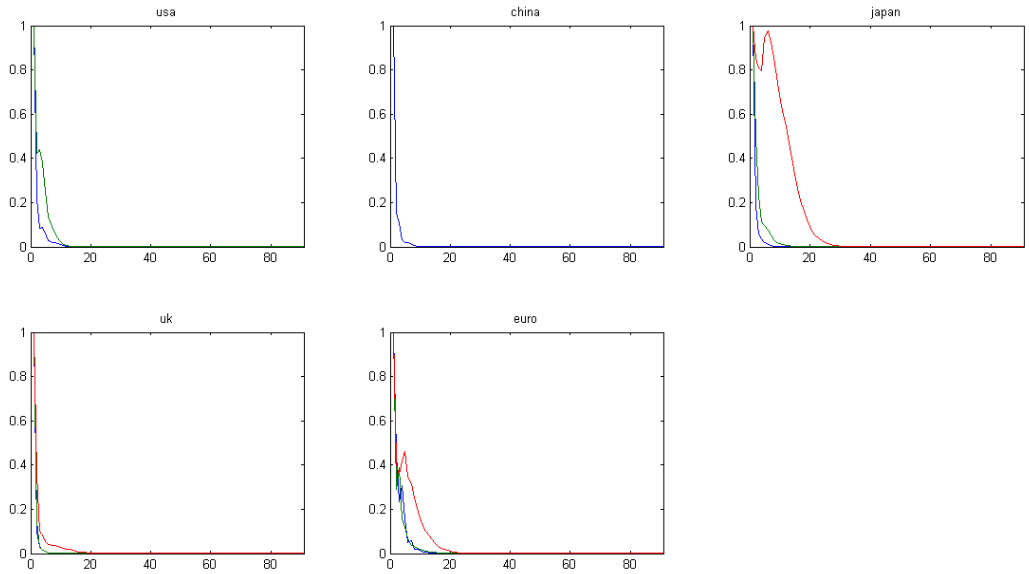

Figure 3: Persistence profiles for the USA, China, Japan, UK and the Euro Area.

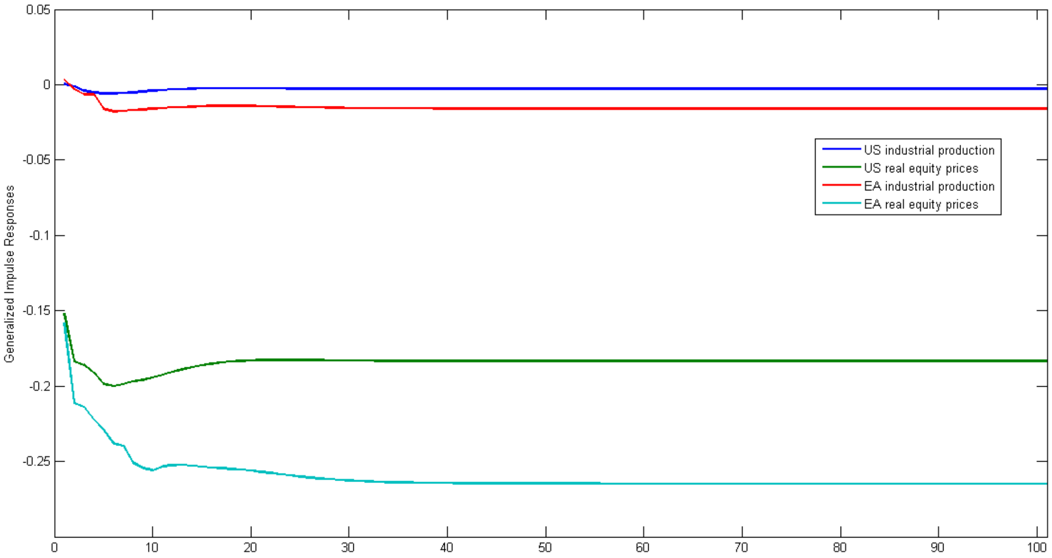

Figure 4: Generalised impulse response functions to a shock to US equity prices.

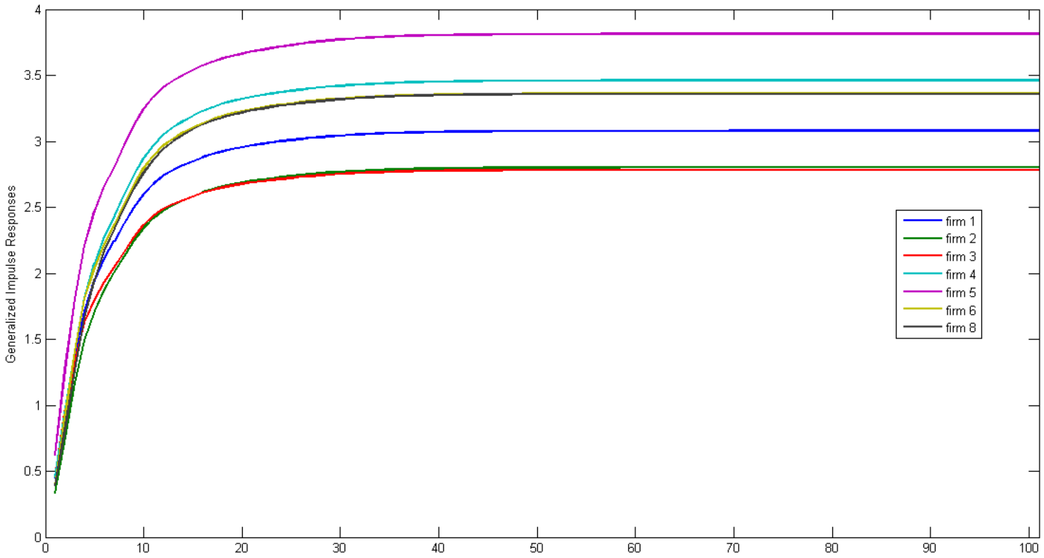

Figure 5: Generalised impulse responses to US equity shock: G-SIFIs.

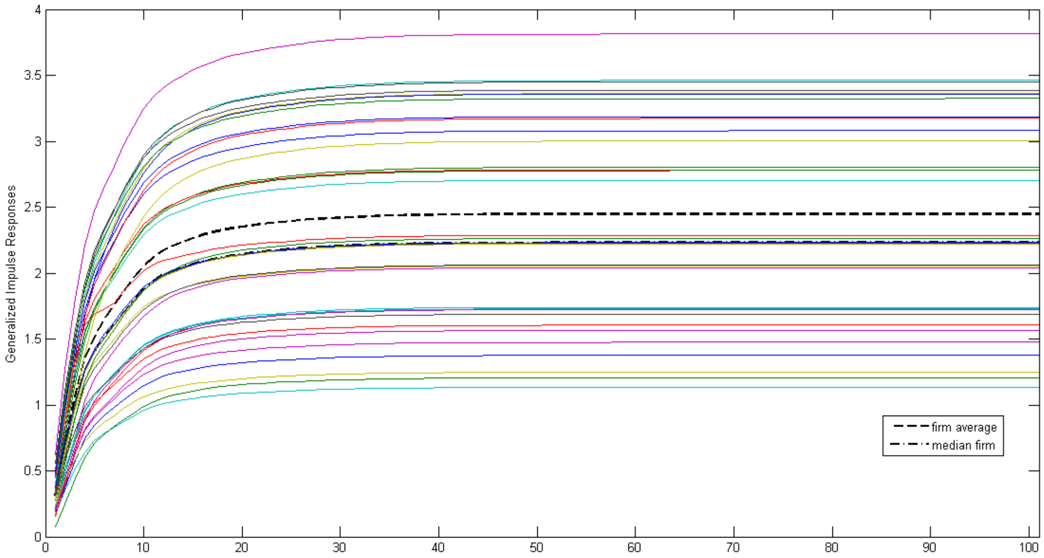

Figure 6: Generalised impulse responses to US equity shock: all firms.

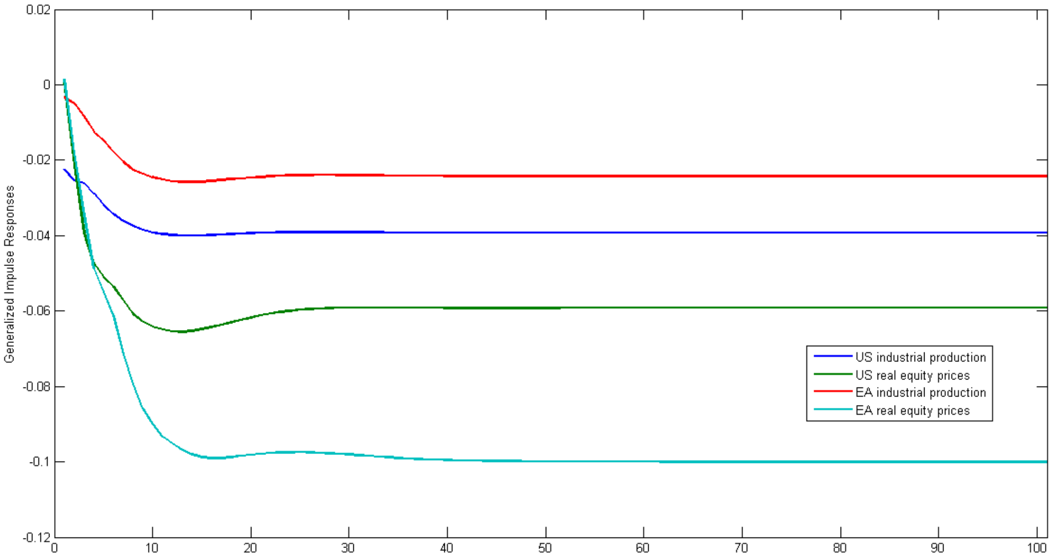

Figure 7: Generalised impulse responses to a negative shock to US industrial production.

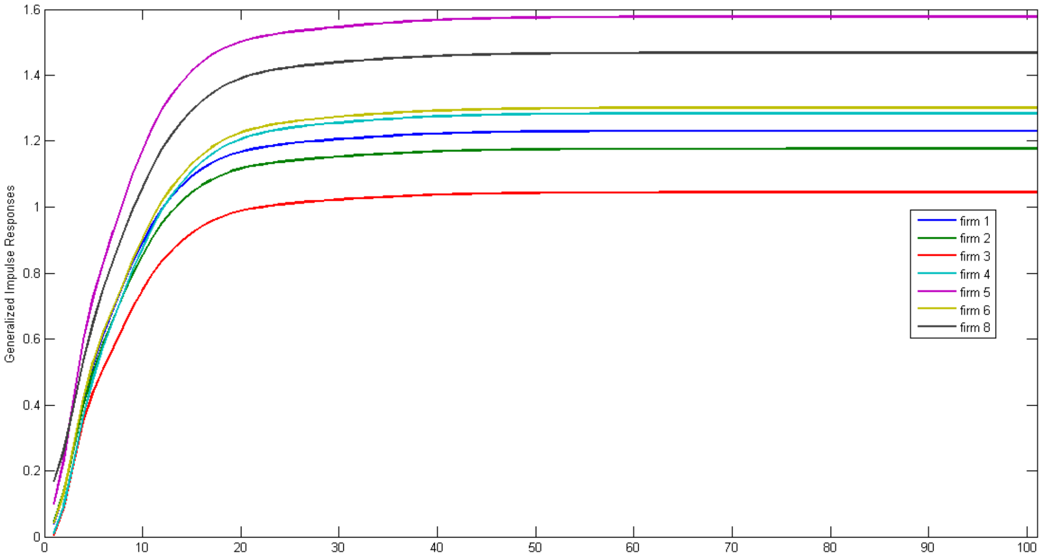

Figure 8: Generalised impulse responses to a negative shock to US industrial production: G-SIFIs.

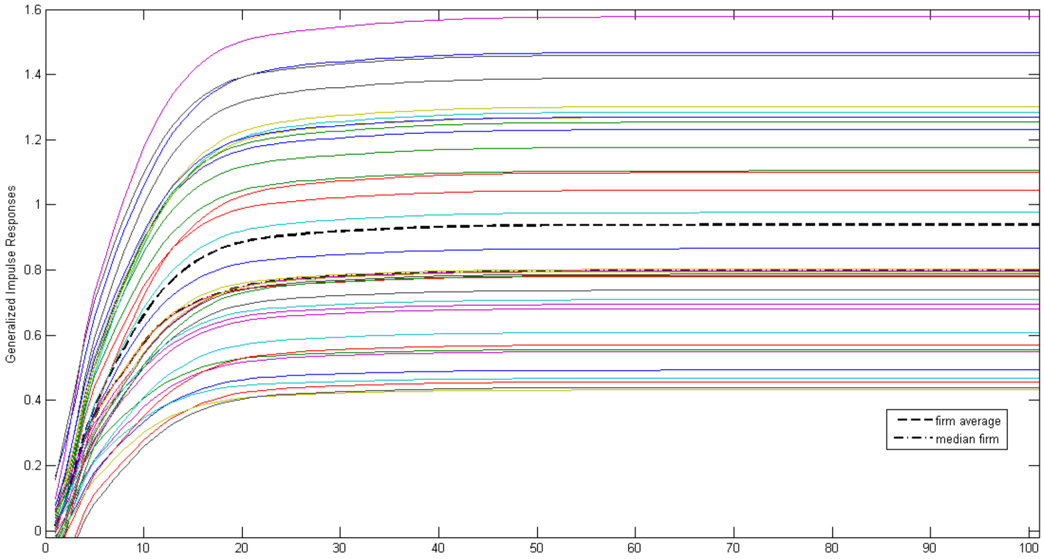

Figure 9: Generalised impulse responses to a negative shock to US industrial production: all firms.

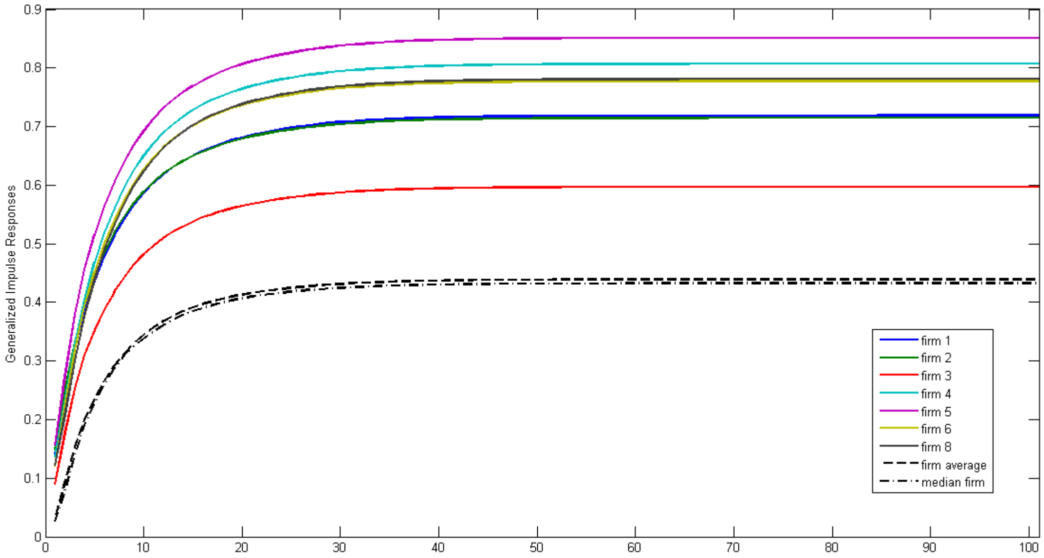

Figure 10: Generalised impulse response to a positive shock to default probabilities of G-SIFIs.

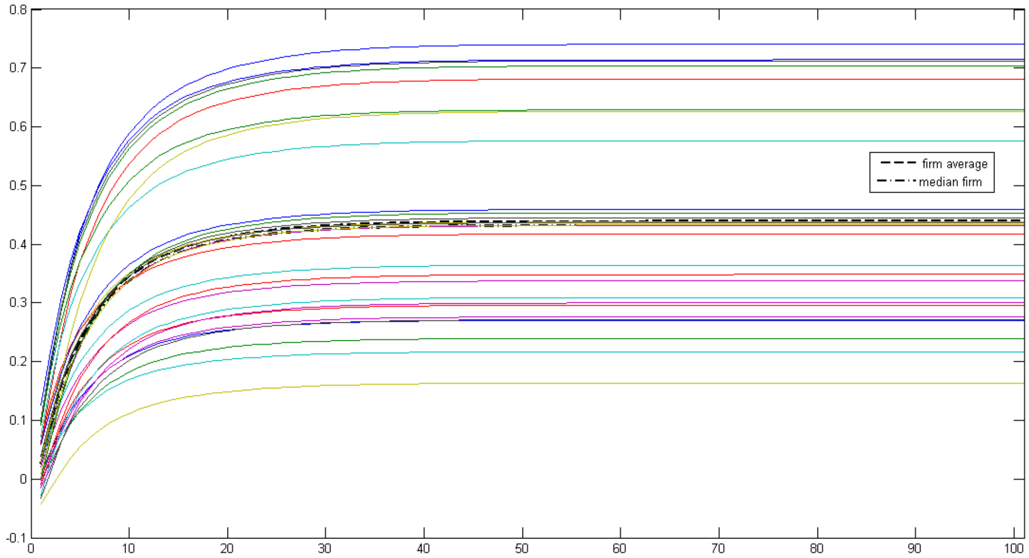

Figure 11: Generalised impulse response functions to a positive shock to PDs of G-SIFIs: remaining firms' responses.

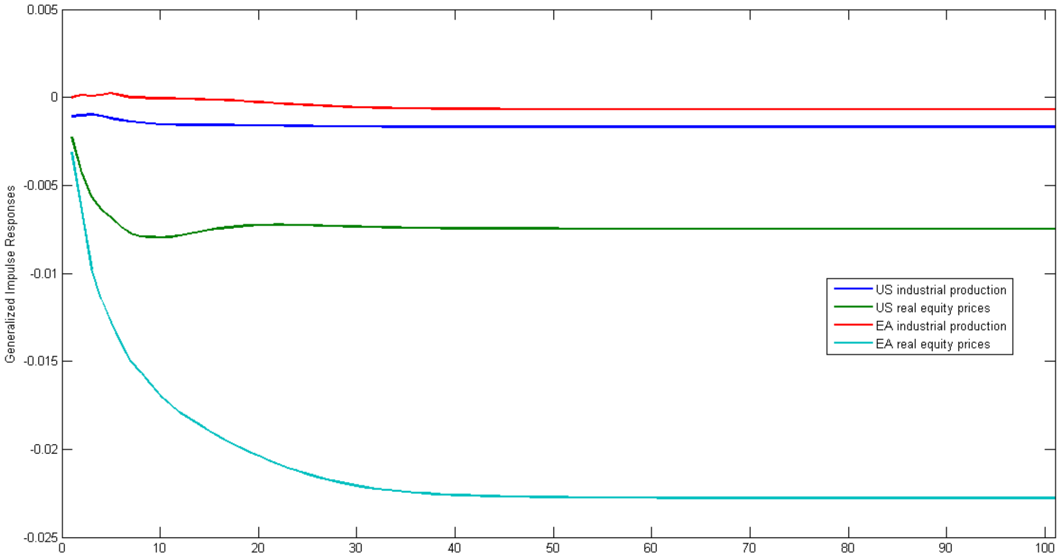

Figure 12: Generalised impulse responses to default probabilities of G-SIFIs: macro response.