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A Network General Equilibrium GVAR Approach

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ABSTRACT: In this work we investigate the dynamic interdependencies among the various EU12 economies using a competitive general equilibrium network system representation. Additionally, using Bayesian techniques, we estimate the autoregressive scheme that characterizes the equilibrium price system of the network, while characterizing each economy/node in the universe of our network in terms of its degree of pervasiveness. In this context, we unveil the dominant(s) unit(s) in our model and estimate the dynamic linkages between the various economies/nodes. Lastly, in terms of robustness analysis, we compare the findings of the degree pervasiveness of each economy against other popular quantitative methods in the literature. According to our findings, the economy of Germany acts as weakly dominant entity in the EU12 economy, which is cross validated by all the techniques employed. Meanwhile, all shocks die out in the short run, without any long lasting effect.

JEL Classification: E1, O5.

Keywords: Bayesian, GVAR, Crisis, Transmission, Debt, EU12

1. Introduction

Inadequate attention has been paid, thus far, to the transmission of the debt crisis among EU12 countries, after the introduction of the Euro currency in 2001 (see *inter alia* Favero, 2013). In brief, the so-called European debt crisis is an ongoing situation that has made it extremely difficult, or even practically impossible, for some countries in the Euro area to repay their debts. Since then, a number of its periphery members such as Greece, Portugal, Ireland, Spain and Cyprus have been severely hit by the economic crisis and austerity measures have been implemented by the so called "Troika" (ECB/EU/IMF). In this spirit, recently, Antonini et *al.* (2013) concluded that the debt dynamics in the EU10 are highly complicated, involving important inter-economy interactions and protracted adjustment periods.

In a prominent paper Cipollini et *al.* (2015) investigated the impact of European Monetary Union (EMU) and of the recent financial and fiscal crisis on the integration of the European sovereign debt market. The results indicated that the elimination of currency risk following the implementation of EMU led to a fundamental and significant one-off increase in integration. In fact, based on their findings, the net impact of fiscal fundamentals was negligible up until 2009 as the markets seemed to be pricing in a potential bailout for member states in crisis and not fully pricing default risk. However, by 2010 the situation of the peripheral economies led the markets to price default risk and heralded a return to segmentation. As a result, the increase in peripheral economy sovereign spreads has exacerbated the problem of fiscal imbalances which pose a major challenge for policy-makers.

At this point, it should be noted that financial institutions are increasingly vulnerable to the fluctuations in the economies in which they operate, especially when these economies face high debt loads. In this context, the European banking sector, especially in the economies that face high public debt loads, still struggles to overcome its inherent dependence from the economic situation of each economy. As a result ECB policy makers try to uncover the appropriate policy actions, using the EFSF mechanism that would allow private banks in specific economies to restructure their assets in an attempt to minimize their overall risk that they face due to their dependence form their respective general governments. Hence, risk analyses of a financial institution's activities need to take into consideration domestic as well as international economic conditions of regions that directly or even indirectly influence the institution loan's portfolio, without neglecting the dominant role of certain economies. This need for careful risk management by banks, insurance companies and pension funds, has led us to develop an updated general equilibrium compact global model capable of offering estimates and scenario analyses for a core set of financial and macroeconomic factors taking into consideration the complex interconnections between national and international factors.

The present work builds on the prominent works of Acemoglu et *al.* (2012), Bailey et *al.* (2016) and Pesaran and Yang (2016). More specifically, in this work we use the network system structure proposed by Acemoglou et *al.* (2012) in order to model the interdependencies between the EU-12 economies using a network general equilibrium framework. Additionally, we investigate the pervasiveness of each economy in the network using the δ-value characterization established by Pesaran and Yang (2016) based on Bailey et *al.* (2016), while extending the modeling choice of Spartial Vector Autoregressive schemes proposed by Pesaran and Yang (2016) by using a GVAR process which acts as a broader infinite approximation of the global factor augmented process. Finally, based on the selection of dominant entities introduced in Tsionas et *al.* (2016) we provide a robustness analysis for the dominance characterization each economy (node) in the network, without ignoring at the same time the estimation results of the general equilibrium equation that characterizes the network through the estimation of the respective GVAR model as a system of equations.

Based on this approach, we check for the transmission of the so-called "debt crisis" between the EU12 economies tracing the timing pattern and the magnitude of the transmission. In this framework, our work estimates: (a) the dominant characterization of each every economy/node in the universe of our model using a δ-value extremum estimator; (b) the link between output and debt fluctuations in EU12, based on a network system of economies that interact in a general equilibrium framework using the global variables of trade and finance which act as the transmission channels.

Of course, the present work builds on previous contributions in the field of GVAR modelling. First, Pesaran and Smith (2006) showed that the VARX* models could be derived as solutions to a DSGE model. Next, Dées et *al.* (2007b) presented tests for controlling for the long-run restrictions within a GVAR context. Furthermore, Chudik and Pesaran (2011) derived the conditions under which the GVAR approach is applicable in a large system of endogenously determined variables. Lastly, Tsionas et *al.* (2016) and Cuaresma et *al.* (2016) were the first papers in the literature that extended GVAR modeling using Bayesian inference.

In comparison to previous contributions, the present work advances the literature in several ways: first, we model by means of a network approach which is based on a general equilibrium framework, the international linkages between the EU12 economies namely: Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal and Spain, while treating Germany as dominant, as dictated by its degree of pervasiveness in the network structure; second, the paper offers a robustness analysis regarding both the existence and the identification of dominant economies (nodes) in the EU12 using the relevant methodologies introduced in Tsionas et *al.* (2016); third, the paper studies the period right after the formation of the European Monetary Union (EMU) and extends the estimation period up to the end of 2015, fully capturing the recent global recession, while acknowledging the impact of global crisis as well as the EU debt crisis through the introduction of the relevant exogenous dummy variables; finally, it is the first study to apply the GVAR approach in a network general equilibrium process for debt issues.

The remainder of the paper is structured as follows: section 2 presents the background literature; section 3 sets out the methodology; section 4 presents the empirical results; section 5 offers a discussion of our findings; finally, section 6 concludes.

2. Background Studies

The investigation of the dynamics of debt as a crucial macroeconomic variable, both theoretically and empirically, has always been a key research topic for many researchers around the globe. In fact, debt as a key macroeconomic variable as well as its linkages with other macroeconomic indicators was first presented in a seminal paper by Fisher (1933). Over the years a vast literature has emerged. See, for instance, Blinder and Solow (1975), Dixit (1976) and Feldstein (1976). Barro (1979) in a seminal contribution developed a debt theory that incorporated the Ricardian invariance theorem.

More recently, Feve and Henin (2000) assessed the question of debt sustainability among G-7 countries by showing that all debts in G-7 countries are sustainable. Giavazzi et *al.* (2000), investigated the non-linear effects of debt reduction policies in OECD economies and showed that structural fiscal policy plans exhibit non-linearities. The optimal fiscal policy regarding contingent-debt was examined by Aiyagari et *al.* (2002) under the complete markets assumption. The debt sustainability based on the inter-temporal budget constraint hypothesis was investigated by Bravo and Silvestre (2002), in eleven (11) EU countries for the time period 1960-2000. Based on their findings Ireland, Portugal, Italy, Finland and Belgium were not in sustainable budget paths. In a similar framework, using data on EU15 for the period 1970-2003, Alfonso (2005) unveiled the sub-optimal nature of fiscal policies adopted in most countries which, in turn, could lead to debt levels that are not sustainable. De Bondt (2005) found that the financing costs, as approximated by the cost of debt securities vis-à-vis other sources of corporate finance, and financing needs, such as captured by mergers and acquisitions and gross domestic product, are the most statistically significant determinants in the short and long run, for corporate debt in EU economies.

The steady state of debt under a new Keynesian regime was investigated by Leight and Wrein-Lewis (2006) who found that debt follows a random walk process. Again Afonso (2007), using data on EU-15 showed that certain countries could face potential debt sustainability problems. In a similar vein, Greiner et *al.* (2007) investigated the debt sustainability of selected

EU economies that exhibited large debt to GDP ratios and/or violated the Maastricht treaty. Their results suggested that all deficits were sustainable. In a prominent work, Arellano (2008) developed a model in a small open economy framework that could predict the relationships between output interest rates and debt that arises in economies that face recession.

Reinhart and Rogoff (2010) investigated thoroughly the link between inflation and both government and external debt showing that inflation is not connected to debt in developed countries. For a critique see Herndon et *al.* (2014). A number of studies have investigated the European debt crisis. See, among others Barrios et al. (2009); Attinasi et *al.* (2010); Ejsing and Lemke. (2011); and Antonini et *al.* (2013). A comprehensive survey on recent literature on fiscal and monetary policy as well as the dynamics of debt in an economy can be found in Eslava et *al.* (2010). Tamakoshi and Hamori (2012) assed impacts of the recent sovereign debt crisis on the time-varying correlations of five European financial institutions holding large amounts of Greek sovereign bonds (National Bank of Greece, BNP Paribas, Dexia, Generali, and Commerzbank). According to their findings, the present of significant increases in the correlations between several combinations of the financial institutions' stock returns after the inception of the sovereign debt crisis, indicating contagion effects, was validated. Finally, Blundell-Wignall (2013) investigated the EMU debt crisis as well as the proposed policies in order to exit the crisis and argued that EMU suffers from two distinct crises: debt and financial.

3. Methodology

3.1 The model

Consider a network with $i = 1, \ldots, N$ nodes where each node represents an economy in an economic system. Each node in this economic network communicates with the rest of the nodes through the edges of the network which can be represented by the input output (IO) Leontief weights. The network evolves in time, i.e. the position of each node (economy) changes over time as a result of a change in the elements of IO weights. In this context, each time stamp $t \in T$ represents a snapshot of the network in time. For the same of simplicity, we assume that the number of network nodes remain fixed over time i.e. no node can neither exit nor enter the network. Following the seminal work of Pesaran and Young (2016), who build on Acemoglu et *al.* (2012) and Bailey et *al.* (2016), we assume, without loss of generality, that each node (economy) produces one good whereas the production process is characterized by a Cobb-Douglas production function:

$$x_{it} = e^{a_{ii}v_{it}} l_{it}^{a_{ii}} \prod_{j=1}^{m-1} x_{ij,t}{}^{a_{ij}w_{ijt}}, i = 1, \ldots, N, \ t \in T \quad \textbf{(1)}$$

where: x_{it} is the produced good of each economy $i = 1, .., N$, a_{ij}, $j, i = 1, .., N$ denote the output elasticities such that $\sum_{j=1}^{J} a_{ij} = 1$, i.e. the production of each economy is characterized by constant returns to scale, $a_{ij}w_{ijt} \geq 0$, $\forall t \in T$ denotes the share of the $j - th$ good used in the production of $i - th$ economy (intermediate good) and v_{it} denotes a productivity shock for economy $i \in I$, which is composed of an economy specific shock ε_{it}, and a common technological factor f_t such that:

$$v_{it} = \varepsilon_{it} + \gamma_i f_t \quad \textbf{(2)}$$

where: γ_i is a factor loading which expresses how the common factor influences each economy $i = 1, \ldots, N$. Following, Pesaran and Yang (2016), we assume that the cross-section exponent of the factor loadings is δ_γ such that the following sequence converges to a positive constant i.e.:

$$N^{\delta_\gamma} \sum_{i \in I} |\gamma_i| \rightarrow c_\gamma > 0 \quad \textbf{(3)}$$

In this set up, if $\delta_\gamma = 1$ then the common factor is pervasive in the sense that it affects all economies (nodes) in the network, otherwise if $\delta_\gamma < 1$ then the common factor is not pervasive, i.e. it does not affect all the economies in the network. Of course, if the factor loadings are random, then we will assume that they follow a random walk pattern i.e. $E(\gamma_i) = 0$ and $Var(\gamma_i) = \sigma_\gamma^2$.

Additionally, we will assume that the economy specific shocks are cross-sectionally independent with zero mean such that $E(\varepsilon_{it}) = 0$ and $Var(\varepsilon_{it}) = \sigma_i^2$.

Turning back to the network structure we will assume that each economy (node) is endowed with one unit of labor, supplied inelastically and has Cobb-Douglas preferences over the N goods produced in the network.

$$u_{it}(c_{1t}, \dots, c_{Nt}) = A \prod_{i=1}^{N} c_{it}{}^{1/m}, i = 1, \dots, N \quad \textbf{(4)}$$

In this set up, the goods produced in the network could be either final goods, c_{it}, or intermediate goods, x_{ijt}, which are used in the production process of at least one economy (node). Therefore, the amount of final goods in the network are defined as:

$$c_{it} = x_{it} - \sum_{j=1}^{N} x_{ijt} \quad \textbf{(5)}$$

In the presence of general equilibrium, we will assume that labor markets clear:

$$l_t = \sum_{i \in I} l_{it} \quad \textbf{(6)}$$

In this context, the competitive equilibrium solution for a given vector of prices, $p = (p_{1t}, \dots, p_{Nt})$ and a wage rate h_t is given by:

$$x_{ijt} = \frac{a_{ij} w_{ij} P_{it}}{P_{jt}} \quad \textbf{(7)}$$

and

$$l_{it} = \frac{a_{ii} P_{it} x_{it}}{H_t} \quad \textbf{(8)}$$

Therefore, by substituting in equation (1) the aforementioned expressions and by simplifying we get:

$$p_{it} = a_{ij} \sum_{j=1}^{M} w_{ij} p_{jt} + a_{ii} h_t - b_i - a_{ii}(\varepsilon_{it} + \gamma_i f_t) \quad \textbf{(9)}$$

where: $p_{it} = \ln(P_{it})$, $h_t = \ln(H_t)$

and $b_i = a_{ii}\ln(a_{ii}) + a_{ij}\ln(a_{ij}) + a_{ij}\sum_{i\in I} w_{ij}\ln(w_{ij})$

We rewrite equation (9), using matrix notation as:

$$\boldsymbol{p_t} = a_{ij}\boldsymbol{W}\boldsymbol{p_t} + a_{ii}h_t\boldsymbol{1} - (\boldsymbol{b} + a_{ii}\boldsymbol{\gamma}f_t + \alpha_{ii}\boldsymbol{\varepsilon_t}) \quad \textbf{(10)}$$

and by solving for the ln-ized price vector we get:

$$\boldsymbol{p_t} = a_{ii}h_t[\boldsymbol{I} - a_{ij}\boldsymbol{W}']^{\boldsymbol{-1}}\boldsymbol{1} + a_{ii}[\boldsymbol{I} - a_{ij}\boldsymbol{W}']^{\boldsymbol{-1}}(-a_{ii}{}^{-1}\boldsymbol{b} + \boldsymbol{\gamma}f_t + \boldsymbol{\varepsilon_t})$$

$$\boldsymbol{p_t} = a_{ii}h_t\boldsymbol{IO1} + a_{ii}\boldsymbol{IOu_t} \quad \textbf{(12)}$$

where: $\boldsymbol{IO} = [\boldsymbol{I} - a_{ij}\boldsymbol{W}']^{\boldsymbol{-1}}$ and $\boldsymbol{u_t} = -a_{ii}{}^{-1}\boldsymbol{b} + \boldsymbol{\gamma}f_t + \boldsymbol{\varepsilon_t}$

The price system described by equation (12) characterizes a network system of economies where each economy is represented by a node, whereas the interconnections between the economies i.e. edges, are represented by the inverse Leontief matrix.

In this context, Pesaran and Yang (2016), propose writing the price equation in (9) as a Spartial Vector Autoregressive (SAR) scheme of the form:

$$\boldsymbol{y_t} = a_{ij}\boldsymbol{W}\boldsymbol{y_t} - \boldsymbol{b}(a_{ij}, \boldsymbol{W}) - a_{ij}(\boldsymbol{\gamma}f_t + \boldsymbol{\varepsilon_t}) \quad \textbf{(13)}$$

where: $\boldsymbol{y_t} = \boldsymbol{p_t} - \boldsymbol{H_t}\boldsymbol{1}$

which represents a SAR(1) scheme with an unobserved common factor, where the price specific interests captured by the vector $\boldsymbol{b}$, depend on the weight matrix $\boldsymbol{W}$ and on a_{ij}. In this context, $\boldsymbol{y_t}$ is captured by a GDP measure according to the related literature.

Pesaran and Yang (2016), based on Bailey at *al.* (2016), characterize the network in terms of strongly and weakly dominant units based on the out degree measure proposed by Acemoglu et *al.* (2012). In detail, a unit in the network is δ_j dominant if its weighted out-degree, is of order N^{δ_j}. In other words, if $\delta_j = 1$ the unit is considered to be strongly dominant, otherwise if $\delta_j \in (0,1)$ is considered to be weakly dominant while non-dominant are the units which exhibit $\delta_j =$

0. In this context, following Pesaran and Yang (2016), we characterize the various economies/nodes of the network in terms of their dominance, using the following scheme (out-degrees):

$$d_{it} = \kappa N^{\delta_i} \exp(v_{it}),\ i = 1, \dots, N \quad \textbf{(14)}$$

$$\kappa = \frac{\exp(-\frac{\sigma_v^2}{2})}{lim_{N\to\infty} N^{-1} \sum_{i=1}^{N} N^{\delta_i}} \quad \textbf{(15)}$$

Of course, equation (14) that characterizes the dominance of each economy (node) in the network, could be consistently estimated using a log transformation.

Additionally, in this paper, we propose a more general representation of the price system described by (13) using a Global Vector Autoregressive scheme, so as to directly estimate the impact of each and every economy (node) in the network to the rest of the economies (nodes). To do so, based on the pioneer work of Dees et *al.* (2007) equation (13) can be represented by a canonical global factor model of the form:

$$y_{it} = \Gamma_i f_t + \xi_{it},\ i = 1, \dots, N \quad \textbf{(16)}$$

where: Γ_i is a matrix of factor loadings which is uniformly bounded i.e. $\|\Gamma_i\| < K < \infty$ and ξ_{it} is a vector of economy (node) specific shocks whereas the factors and the economy/node specific shocks assume to follow:

$$\Delta f_t = \Lambda_f(L)\eta_f,\ \eta_f \sim IID(0, I) \quad \textbf{(17)}$$

$$\Delta \xi_{it} = \Xi_i(L)\omega_{it},\ \omega_{it} \sim IID(0, I) \quad \textbf{(18)}$$

where Λ_f and Ξ_i are uniformly absolute summable, so as to ensure the existence of $Var(\Delta f_t)$ and $Var(\Delta \xi_{it})$. Under these assumptions, Dees et al. (2007) showed that the unobserved common factors could be consistently estimated by linear combinations of cross section averages of the observable variables y_{it} given in (14) as:

$$y_{it}^* = W_i' y_{it} = \Gamma_i^* f_t + \xi_{it}^* \quad \textbf{(19)}$$

Therefore, they obtained the economy specific VAR augmented models with $y_{it}{}^{*}$:

$$\Phi_i(L, p_i)(y_{it} - \widetilde{\delta_\iota} - \widetilde{\Gamma_\iota^*} y_{it}{}^*) \approx \omega_{it} \quad \textbf{(20)}$$

which corresponds to a conditional VARX model for each economy (node) in the network of the form:

$$\underset{(1\times m)}{y'_{it}} = \underset{(1xm)}{a_{iO}} + \sum_{l=1}^{L_1} y'_{i,t-l} \underset{(m\times m)}{A_{il}} + \sum_{l=0}^{L_2} y^{*'}_{i,t-l} \underset{(m\times m)}{B_{il}} + \sum_{l=0}^{L_3} \underset{(1\times k)}{x'_{t-l}} \underset{(k\times m)}{C_{il}} + u'_{it} \quad \textbf{[21]}$$

where a_{i0} denotes a (*1xm*) vector of *m* intercepts, $\underset{(1\times m)}{y'_{it}} = \left[y_{i,t_1}, \ldots, y_{i,t_m} \right]$ denotes the transposed of a (*mx1*) vector $y_{i,t}$ of m variables for economy i expressing the so-called endogenous variables; $\underset{(1\times m)}{y^{*'}_{i,t}} = \left[y^*_{i,t_1}, \ldots, y^*_{i,t_m} \right]$ denotes the transposed of a (*mx1*) vector $y^*_{i,t}$, of m foreign-specific variables, and $x'_t = \left[x_{t_1}, \ldots, x_{t_k} \right]$ denotes the transposed of a (*kx1*) vector of *k* global variables. In general, the *m* and *k* may be allowed to vary between countries i, that is m_i and k_i for each economy $i = 1, \ldots, N$.

In what follows we summarize the Bayesian estimation of the GVAR scheme that characterizes the general equilibrium solution of the network economy constructed, following briefly Tsionas et *al.* (2016).

3.2 Bayesian estimation

The GVAR model can be written in the form:

$$y'_{it} = \underset{(1\times K)}{z'_{it}} \underset{(K\times m)}{\Gamma_i} + u'_i$$

where $K = L_1 + L_2 + L_3 + 2$, and

$$z'_{it} = \left[y'_{i,t-1},..., y'_{i,t-L_1}, y^{*'}_{i,t}, y^{*'}_{i,t-1},..., y^{*'}_{i,t-L_2}, x'_t, x'_{t-1},..., x'_{i,t-L_3} \right].$$

Next we get:

$$\underset{(T\times m)}{Y_i} = \underset{(T\times K)}{Z_i} \Gamma_i + U_i \,,\; i = 1,...,N \quad \textbf{[22]}$$

corresponding to a multivariate model. This can be written as follows:

$$\underset{(Tm\times 1)}{y_i} = \left(I \otimes Z_i\right) \underset{(Km\times 1)}{\gamma_i} + u_i \,,\; i = 1,...,N \quad \textbf{[23]}$$

where $u_i \sim N\left(O, \Sigma_{ii} \otimes I\right)$, and Σ_{ii} is an $m \times m$ covariance matrix for the i economy leading to the following compact representation:

$$\underset{(NTm\times 1)}{Y} = X \underset{(NT\times Km)}{\gamma} + u \quad \textbf{[24]}$$

where the covariance is:

$$\begin{bmatrix} u'_{t1} \\ . \\ . \\ . \\ u'_{tN} \end{bmatrix} \sim N(0, \underset{(Nm\times Nm)}{\Omega} = \begin{bmatrix} \Sigma_{11} \; \Sigma_{12} & ... & \Sigma_{1N} \\ \Sigma_{12} \;\; \Sigma_{22} & ... & \Sigma_{2N} \\ \Sigma_{1N} \;\; \Sigma_{2N} & ... & \Sigma_{NN} \end{bmatrix})$$

and each $\underset{(m\times m)}{\Sigma_{ij}}$, represents a covariance matrix between the error terms of countries i and j.

Also, $X = \begin{bmatrix} X_1 \\ X_2 \\ . \\ . \\ . \\ X_N \end{bmatrix}$ and $\gamma = \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ . \\ . \\ . \\ \gamma_N \end{bmatrix}$.

Hence we get:

$$y'_{it} = \tilde{z}'_{it}\tilde{\Gamma}_i + z^{*'}_{it}\Delta_i + u'_{it} \quad \textbf{[25]}$$

and $z^{*'}_{it} = \left[y^{*'}_{i,t}, y^{*'}_{i,t-1}, \ldots, y^{*'}_{i,t-L_2}\right]$ expresses the foreign specific variables, and $\tilde{z}'_{it}$ represents the own lags and the global variables. Now, the model is:

$$Y_i = \tilde{Z}_i\tilde{\Gamma}_i + Z^*_i\Delta_i + U_i, \; i = 1,\ldots,N \text{ , or} \quad \textbf{[26]}$$

$$y_i = \left(I \otimes \tilde{Z}_i\right)\tilde{\gamma}_i + \left(I \otimes Z^*_i\right)\delta_i + u_i = \tilde{X}_i\tilde{\gamma}_i + X^*_i\delta_i + u_i, \; i = 1,\ldots,N \; \textbf{[27]}$$

Also:

$$y^{*'}_{it} = \sum_{c=1}^{N} w_{ic}y'_{ct} = w'_{it} \underset{(N\times m)}{Y_t} \; \textbf{[28]}$$

where: w_i represents the vector of trade weights of economy i with every economy $c \neq i = 1,\ldots,N-1$, with $w_{ii} = 0$, $\sum_{c\neq i} w_{ic} = 1$. Now:

$$y^{*'}_{1t} = w'_{1t} \underset{(N\times m)}{Y_t},$$

$$y^{*'}_{2t} = w'_{2t} \underset{(N\times m)}{Y_t},$$

$$\ldots$$

$$y^{*'}_{Nt} = w'_{Nt} \underset{(N\times m)}{Y_t} \; \textbf{[29]}$$

In summation:

$$\underset{(N\times m)}{Y^*_t} = \underset{(N\times N)}{W_t} Y_t \; \textbf{[30]}$$

Where W represents the $N \times N$ matrix of weights, and Y_t^* is an $N \times m$ matrix whose rows represent the m foreign – specific variables, for a given observation.

The likelihood function of the system[1] is:

$$L(\gamma, \Omega) = |\Omega|^{-T/2} \exp\left\{-\tfrac{1}{2} tr(Y - X\Gamma)' \Omega^{-1}(Y - X\Gamma)\right\} \propto$$

$$|\Omega|^{-T/2} \exp\left\{-\tfrac{1}{2}(\gamma - \hat{\gamma})' \left(\Omega^{-1} \otimes X'X\right)(\gamma - \hat{\gamma})\right\} |\Omega|^{-(T-p)/2} \exp\left\{-\tfrac{1}{2} tr\Omega^{-1}(Y - X\Gamma)'(Y - X\Gamma)\right\} \propto$$

$$N\left(\gamma \mid \hat{\gamma}, \Omega \otimes (X'X)^{-1}\right) \times IW\Big(\Omega \mid (Y - X\Gamma)'(Y - X\Gamma), \mathrm{N}Tm - (\mathrm{K}x + m + 1)\Big),$$

and IW is the inverted Wishart

$$\Gamma = \left[\tilde{\gamma}_1 \ \ldots \ \tilde{\gamma}_N \ldots \tilde{\delta}_1 \ \ldots \tilde{\delta}_n\right], \ X = \begin{bmatrix} \tilde{X}_1 \\ \\ \ldots \\ \\ \tilde{X}_N \\ \tilde{Z}_1 \\ \ldots \\ \tilde{Z}_N{}^* \end{bmatrix} \quad \textbf{[31]}$$

$$X_i = I \otimes Z_i, \ i = 1, \ldots, N$$

Ever since West (1987) or Feller (1966, par. 6.2, p. 170) we have :

$$\tfrac{a}{2} \exp\{-a|z|\} = \int_0^\infty \left(2\pi v^2\right)^{-1/2} v^2 \exp\left\{-\tfrac{a^2}{2}\right\} \frac{a^2}{2} dv, \ a > 0$$

and therefore: $Z \mid \tau^2 \sim N(0, \tau^2)$ and independently $\tau^2 \sim Exp\left(\frac{\lambda^2}{2}\right)$ then Z follows a Laplace distribution which in the context of linear regression yields the LASSO:

[1] For a single country see Kadiyala and Carlsson (1997, p. 101) and Koop (2013, pp. 178-179 and 195-199) or Korobilis (2013b, p. 4).

$$\min : (y - X\beta)'(y - X\beta) + \lambda \sum_{j=1}^{k} |\beta_j|$$

This is used in a Bayesian context to impose priors in the context of Bayesian vector autoregressions. Koop (2013, pp. 197-199) describes a procedure, which has the standard decomposition $\Sigma^{-1} = \Psi\Psi'$ and Ψ is upper-triangular. For the diagonal elements he assumes independent gamma priors of the form $\psi_{jj}^2 \sim G(1,1)$ if data are standardized. For the off-diagonal elements he proposes an SSVS prior which is essentially N(0,1) or N(0,0.1) with equal probabilities ½. Recently, Huang and Wand (2013) have proposed a prior for large sparse positive definite matrices where control is allowed over the standard deviations and the correlation coefficients:

$$\underset{(K' \times K')}{\Sigma} \mid a_1,...a_p \sim IW\left(\overline{A}, \nu + K' - 1\right) \textbf{ [32]}$$

where $\overline{A} = 2\nu diag\left(a_1^{-1},...,a_{K'}^{-1}\right)$, where K=Km

$$a_k \sim IG\left(\tfrac{1}{2}, \tfrac{1}{A_k^2}\right), k = 1,.., K' \quad \textbf{[33]}$$

where the density of the Wishart $W(k, S)$ which is:

$$p(\Sigma) \propto |S|^{k/2} \exp\left\{-\tfrac{1}{2} trS\Sigma^{-1}\right\},\ k > 0 \quad \textbf{[34]}$$

and Σ, S are positive definite matrices.

Large values of $A_1,..., A_p$ imply weakly informative priors on the standard deviations while the choice $\nu = 2$ leads to uniform priors on the correlation coefficients. The explicit form of the prior is:

$$p(\Sigma) \propto |\Sigma|^{-(\nu+2K')/2} \prod_{k=1}^{\nu} \left\{\tfrac{1}{A_k^2} + \nu\left(\Sigma^{-1}\right)_{kk}\right\}^{-(\nu+K')/2} \quad \textbf{[35]}$$

The marginal distribution of each correlation coefficient is

$$p(\rho_{ij}) \propto (1-\rho_{ij}^2)^{\frac{\nu}{2}-1}, \ -1 < \rho_{ij} < 1 \ \textbf{[36]}$$

Also, the marginal distribution of each standard deviation follows a half-*t* distribution with parameters ν, A_k, that is:

$$\sigma_{ii}^2 \mid a_i \sim IW\left(\nu, \tfrac{2\nu}{a_i}\right), \text{ and independently } a_i \sim IG\left(\tfrac{1}{2}, \tfrac{1}{A_i^2}\right), \ i = 1,\ldots,K' \ \textbf{[37]}$$

The important property is that its conditional distribution is still inverse Wishart and the posterior conditionals of a_is are inverse-Gamma distributions (Huang and Wand, 2013, p. 7). Therefore, Gibbs sampling can be implemented easily.

Moreover, the posterior conditional distributions of weights in W_t can be drawn en bloc using a Gibbs sampler update relying on the Kalman filter. This procedure reduced considerably the autocorrelation inherent in MCMC and, in lags of order 50, it was negligible.

In detail, in this work the model consists of twelve (12) major economic entities (nodes) namely Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal and Spain. Each economy *i,* $i = 1,\ldots,12$, follows a VAR scheme, augmented by the exogenous variables of global trade (T) and global stocks traded (S), expressing the transmission channels of trade and finance, respectively.

The endogenous variables y_{it} denote a 12×1 vector of macroeconomic variables belonging to each economy *i,* $i = 1,\ldots,12$, consisting of Gross Domestic Product (GDP) and Debt (D) that can perfectly capture the price system of the general equilibrium equation, and are regressed: on an intercept a_{i0}, on their lags up to the order L_1, the contemporaneous and lagged up to the order L_2 foreign variables $y^*{}_{i,t}$, and some contemporaneous and lagged up to the order L_3 common global factors x_t. The error term u'_{it} is assumed to be normally distributed with mean zero and the variance-covariance matrix.

The foreign variables $y^{*}_{i,t}$ represent a weighted average of the other economy's variables. Thus, the VARX model for each economy using the notation presented earlier is as follows:

$$y'_{it} = a_i + \Phi_i(L, L_1)y'_{it} + \Lambda_i(L, L_2)y^{*\prime}_{it} + \Psi_i(L, L_3)x_t + u_{it} \quad \textbf{[38]}$$

For $\mathrm{i} = 1, \dots 12$ and $\mathrm{t} = 1, \dots \mathrm{T}$; where $\Phi_\mathrm{i}(\mathrm{L}, \mathrm{L}_1)$, $\Psi_i(L, L_2)$ and $\Lambda_i(L, L_3)$ are the matrixes of the lag polynomial of the associated coefficients of the economy-specific, of the foreign, and of the global variables, respectively. In this work, matrix W_i is a 12 × 12 dimensional matrix of weights that defines k_i=12 economy-specific cross section averages of foreign variables. Lastly, u_{it} is a vector of idiosyncratic, serially uncorrelated economy-specific shocks with $u_{it} \sim N(0, \Sigma)$,

The dynamic characteristic of the model are examined through the so-called Generalized Impulse Response Functions[2] (GIRFs) following Koop et *al.* (1996) and Pesaran and Shin (1998). A basic advantage of this approach is that the GIRFs are invariant to the ordering of the equations. The (Generalized) Impulse Response Function (GIRF) can be expressed as follows:

$$I_{j\,(n)} = \sigma_{jj}{}^{-1/2} + B_n \Sigma e_j \forall n = 1, 2, \dots \quad \textbf{[39]}$$

where $I_{j\,(n)}$ is the Impulse Response Function *n* periods after a positive standard error unit shock; σ_{jj} is the *j*th row and *j*th column element of the variance–covariance matrix Σ of the lower Cholesky decomposition matrix of the error term which is assumed to be normally distributed; B is the coefficients' matrix when inversely expressing the VAR model as an equivalent MA process and e_j is the column vector of a unity matrix. See Koop et *al.* (1996) and Pesaran and Shin (1998). Simulation from their posterior distribution is straightforward.

[2] As in GVAR applications, we prefer GIRFs over more standard orthogonalized impulse responses (OIRs), which would require the definition of an ordering of the variables in the reduced form VAR, (see *inter alia* Dovern and Roye, 2014)

In what follows, we provide a robustness analysis in terms of characterization of the dominant units of the network.

3.3 Robustness Analysis

Number of dominant entities in the network

We investigate the eigenvalue distribution of the weight matrix that comes directly by the Input Output weight matrix which is publically available at WIOD. The eigenvalue distribution of the IO weight matrix expresses the dynamic behavior of all the EU12 economies that enter our analysis (Brody 1997). Let λ(i), denote the eigenvalues of the Weight matrix that characterizes the interconnections of the network and let λ(pf) = λ(1) denote the dominant or so-called Perron–Frobenius (P–F) eigenvalue of the *n* × *n* matrix *W*. We divide each eigenvalue's modulus with the P-F eigenvalue's modulus to get the normalized eigenvalue: $\rho(i) = |\lambda(i)\,| \cdot |\lambda(pf)\,|^{-1}$, i=1,...,12. The normalized eigenvalues: ρ(i), i=2,...,12 are the so-called *non*-dominant eigenvalues, since ρ(pf)=ρ(1)=1, is the dominant one.

The number of dominant economies implied by the economy's structure is equal to i^*, for which $\rho(i^*)$>0.4-0.3 approximately, since values of $\rho(i^*)$ less than 0.40–0.30 might be considered negligible from a practical point of view (Brody 1997΄Mariolis and Tsoulfidis, 2014).

Next, based on the concept of centrality (Freeman 1979), we examine which economies are dominant by using two main vertex theory measures, namely: (i) degree centrality and (ii) eigenvector centrality.

(i) The degree centrality of a node indicates how connected a node is to the other nodes in the graph (see, among others, Ying et *al.* 2014; Bates et *al.* 2014). The centrality, c_i, of each node is given by the following formula:

$$c_i = d(i)\sum_{j=1}^{N} z_{ij} \quad \textbf{[40]}$$

where $d(i)$ is the degree of each node i.e. the number of ties with the rest of the nodes (Fagiolo et *al.* 2008). In this context, the dominant economies are those which exhibit the largest centrality. Hence, the largest c_i corresponds to the dominant economy, the second largest c_i to the second-dominant economy, and so on.

However, degree centrality does not take into consideration how the neighbors of each node interact with the rest of the nodes of the vertex. In this context, we take into consideration an additional measure of node centrality namely, eigenvector centrality (Bonacich and Lloyd, 2001).

(ii) **Eigenvector centrality** of a node, i, was developed by Bonacich (1987) and can identify the centrality power of a node according to the distant neighbors of the specific node. It is given by the following formula:

$$EC_i = \lambda^{-1} \sum_{j=1}^{N} A_{ij} e_j \quad \textbf{[41]}$$

where: λ^{-1} is the inverse of the Perron-Frobenious eigenvalue of the adjacent matrix, e_j the respective eigenvector,. $A_{ij} = [z_{ij}], i, j \in \{1, \ldots, N\}$ is the adjacency matrix. Apparently, dominant economies are those with the largest values of eigenvector centrality.

4. Empirical Results

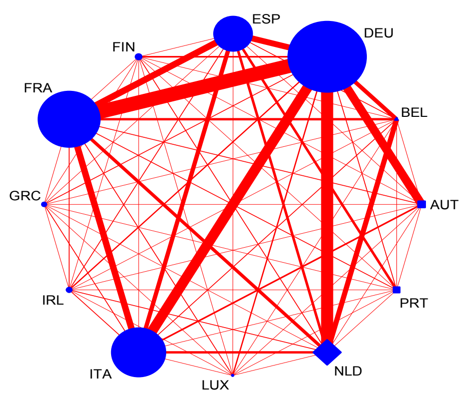
4.1 Data and Variables

The data come from IMF, are quarterly, and cover the period 2001–2015 after the introduction of the common currency, fully capturing the recent recession. In order to consistently estimate the general equilibrium price equation of the network system of economies we make use of two (2) economy-specific variables for each economy: GDP and Debt, which can fully capture the log difference of prices and wages in an economy, following the general spirit of Long and Plosser (1983). In this context, the variable of Debt is an aggregation of various Debt forms i.e. banks' debt, government debt and monetary authorities' debt. Regarding the global variables, we use the aggregate values of (i) *Worldwide Total Trade* and (ii) *Worldwide Total Stocks Traded,* both in millions of dollars, which were obtained in constant 2005 prices from the World Data Bank[3]. All variables under investigation were transformed to constant 2005 prices in billions of dollars using the GDP deflator for every economy in the universe of our model, whereas all quantitative variables were also transformed according to the logarithmic transformation. Additionally, in order to avoid any structural instability we incorporated in every VARX model the dummy variable of Global crisis as well as the European Debt crisis. Additionally, dummy variables for the presence of local crises were also employed in the VARX models of Greece, Portugal and Spain and Ireland.

4.2 The Network

Figure 1 below presents the EU12 weighted network as set out earlier.

Figure 1: Network plot of EU12 economies



The network's structure is cyclical since all nodes interconnect with each other. As it can be seen, the economies of Germany, Spain, France and Italy are the largest economies in our network with respect to the weight out degrees of the network.

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[3] Whenever quarterly data were missing, quarterly series were interpolated from the annual series following Dees et *al.* (2005).

4.3 Degree of Pervasiveness

Following Pesaran and Yang (2016) we characterize each and every economy (node) in the network in terms of its pervasiveness based on its δ-value.

Table 1: Degree of pervasiveness

Economies (Nodes)	Rank based on δ-value Pervasiveness
AUT	7
BEL	6
DEU	1
ESP	5
FIN	10
FRA	2
GRC	12
IRL	8
ITA	4
LUX	11
NLD	3
PRT	9

Based on our findings, the economy of Germany is the only economy that exhibits the largest δ-value according to Pesaran and Yang (2016) (weakly dominant).

Following the methodologies described earlier, we investigate the eigenvalue distribution of the Input Output matrix, in order to verify the existence of a dominant entity. We begin by investigation for the existence of a dominant economy in the data set. In this context, Table 1 below, presents the normalized eigenvalues of the Weight matrix W for 2005.

Table 2: Normalized Eigenvalues of *W*(2005)

Eigenvalue	ρ_i
1	1
2	0.041
3	0.031
4	0.027
5	0.001
6	0.001
7	0.004
8	0.000
9	0.001

10	0.003
11	0.002
12	0.002

The results imply the existence of one dominant economy in the EU12, since values of ρ(i) less than 0.40–0.30 are considered negligible from a practical point of view (Brody 1997 and Mariolis and Tsoulfidis, 2014).

We proceed by investigating the centrality measures.

Table 3: Centrality measures based on the average matrix *W*

Economies	Degree centrality	Eigenvector Centrality
AUT	0.0056	0.015
BEL	0.0119	0.027
DEU	0.0299	0.053
ESP	0.0119	0.025
FIN	0.0019	0.004
FRA	0.0183	0.041
GRC	0.0016	0.004
IRL	0.0029	0.006
ITA	0.0133	0.030
LUX	0.0019	0.004
NLD	0.0155	0.035
PRT	0.0027	0.005

According to the results of Table 3, for both centrality measures, the German economy is dominant in our model, since it exhibits the largest values of degree and eigenvector centrality. Of course, the selection of Germany as the dominant economy in our dataset can also be easily justified by economic intuition based on the latest economic and political developments as of 2013 since: (a) it is the largest economy in terms of output *produced*, as well as (b) the largest economy in terms of output *exchanged.*

In fact, the EU economy contains about 500 million people and is the largest trading area in the world. Within this economic entity, Germany has the largest population and the largest economy in the EU. In the world, the German economy ranks 4th in terms of nominal GDP and is the world's 2nd largest trader (CIA, 2013) in terms of imports and exports, close to the spirit of the traditional GVAR model. As is known, the most important driving forces in the German economy are primarily the industrial and banking sectors that have allowed the local economy to dominate the vehicles, machinery and equipment industries globally.

In the EU market, currently, the German economy is undoubtedly dominant, a fact which is largely the product of stable growth export-oriented productive industries, a relatively big and powerful public sector with considerable private sector partnership, where the workers' unions play a role in management. It is also characterized by a well-known aversion to high indebtedness often viewed as being synonymous with economic rationality.

All things considered, the robustness analysis for the dominant economy in the network verifies the findings based on the δ-value of Pesaran and Young (2016). It is worth noticing, that the δ-value characterization of each economy coincides with the results obtained by degree centrality measure.

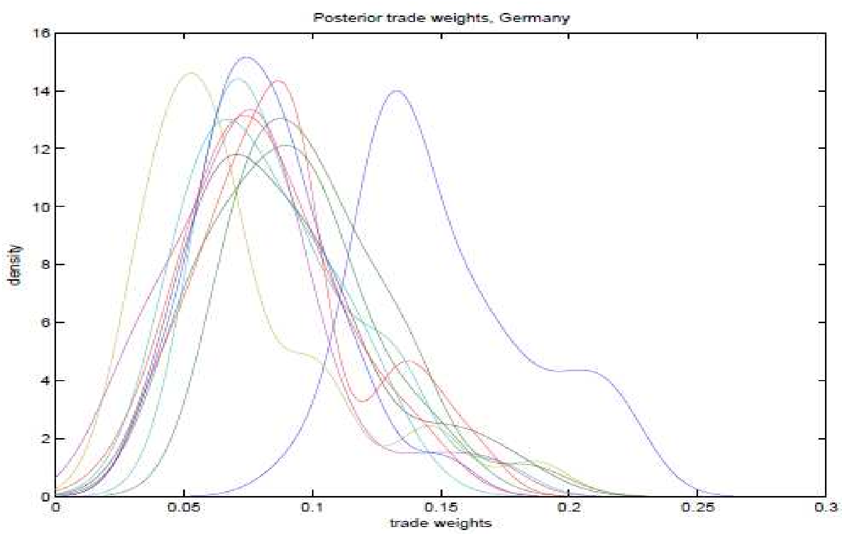
4.4 Weights

We consider time varying weights, which are based in a raw benchmark set of weights $\bar{w}_{ic,t}$ and assume the following process:

$$w_{ic,t} = \rho_{ic} w_{ic,t-1} + \alpha_{ic} \bar{w}_{ic,t} + \varepsilon_{it}$$

Posterior weights for Germany, using the proposed approach, are presented in Figure 2[4]. The posterior distribution of the weights is characteristically bimodal reflecting the combination of information from the data and evidence through the calibrated prior.

Figure 2: Posterior Trade weights for Germany



4.5 Generalized Impulse Response Function (GIRFs)

Given that the VARs contain a large number of parameters, principled priors have to be introduced on the parameters, especially in relatively small data sets. Here, we follow Tsionas et *al.* (2016). The forecasting performance of the models is examined in the hold-out sample and the model with the smallest mean-squared-forecast-error is selected. Our implementation of the Metropolis-Hastings algorithm relies on: (i) a component-wise update from the conditional

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[4] All credible intervals for GIRFs are computed using the set of draws, thinning every other 10th draw. Similar posteriors were computed for every country in the model but we do not report the results due to space limitations. Of course, the results are available upon request by the authors.

posterior distribution of each parameter in C , (ii) a multivariate normal proposal for all other parameters[5] using 10,000+B draws the first B of which are discarded to mitigate the impact of start-up effects. B is chosen according to Geweke's (1992) convergence diagnostics.

The number of lags (L_1, L_2, L_3) is chosen randomly from the prior, which is not very different from conditioning on values of these lags and performing posterior analysis for the given values. The proposal for each MCMC update of the parameters is a uniform distribution in an interval of the form $[a,b]$, which is updated during the transient phase to achieve acceptance rates between 20% and 30%. In our application, M=10,000 models are examined in total. Typically the value of B ranged between 2,500 and 5,000, depending on the model[6].

We have computed Generalized Impulse Response Functions (GIRFs)[7] for the models that performed best. The *final* GIRFs were computed using model averaging where the weights are computed from the marginal likelihood of each model. The marginal likelihood is computed, for each model, using the candidate's formula with a normal approximation to the exact posterior of the parameters following DiCiccio et *al.* (1997). This procedure is fast and easy to apply, which is important in this context where repeated MCMC simulations have to be considered. Standard errors of the GIRFs are computed in standard fashion using the posterior draws for the parameters[8] and the subsequent computation of GIRFs for each draw, after thinning every other 10th draw to mitigate inherent autocorrelation induced by MCMC.

Now, we base our analysis of Generalized Impulse Response Function (GIRFs) on the Bayes confidence bounds rather than the point estimates in order to avoid any possible structural instability. In this context, a GIRF diverges significantly, if and only if zero does not belong to the confidence interval. Finally, we will need to ensure the robustness of our GIRFs results to the weights.

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[5]All other parameters are regression-like parameters in the VAR. The multivariate normal proposal was crafted using least squares quantities and its scaled covariance matrix, where the scaling constant is adapted during the transient phase.
[6] MCMC procedures performed very well and convergence was fast.
[7] The method avoids the drawback of Cholesky decomposition see Koop, Pesaran and Potter (1996).
[8] We use a Newey-West HAC estimator with 10 lags applied to the draws for GIRFs.

Each GIRF shows the dynamic response of the output of each region to unit shocks to each EU12 economy's: (i) Debt and (ii) GDP of up to 16 periods, i.e. 4 years. In the exposition of the results, the reader can focus on the first two years following the shock, which is a reasonable time horizon over which the model presents credible results (Dees et *al.* 2007a). However, according to the same authors (Dees et *al.* 2007a), in what follows we provide an analysis of the results over a period of four years, since visual inspection of the results help us with the analysis of the proposed model's convergence properties(see among others Dovern and Roye, 2014). Figures 1-12 show the posterior mean estimates of the GIRFs as well as their associated 95% Bayes intervals, regarding the response of every economy's GDP to an impact on the GDPs and Debts of the rest of the countries. In this context, GDP is significantly affected when the 95% Bayes interval does not include zero.

In order to avoid complex notation we made use of the following code numbers instead of economy names, see Table 4.

Table 4: Economy code numbers

Code Number	Economy/Node
1	AUSTRIA
2	BELGIUM
3	FINLAND
4	FRANCE
5	GERMANY
6	GREECE
7	IRELAND
8	ITALY
9	LUXEMBOURG
10	NETHERLANDS
11	PORTUGAL
12	SPAIN

5. Discussion

Figure A1 suggests that the Austrian GDP is significantly affected, in the short run by a shock in the Debt of France, whereas it is affected by the GDPs of the of EU12 economies with the exception of the GDPs of Greece and Ireland. The significant impact of the shock in the Debt of France could be attributed to the high degree of financial integration between the two economies since a number of French Banks have an active role in the economy of Austria. Nevertheless, in all cases, the Austrian GDP returns back to its initial equilibrium position in the medium run, i.e in less than 8 quarters.

Next, turning to Figure A2, the results suggest that the GDP of Belgium is significantly affected, in the short run, i.e. less than four (4) quarters by a shock in the Debt of Austria, Finland, France and Italy, whereas its GDP is significantly affected by the majority of the EU12 GDPs, with the exceptions of Greece and Ireland. The relations of Belgian GDP with the rest of the EU12 economies could be attributed to the strong trade relationships or to the financial integration between them. An interesting result, is the absence of relationship between Belgium and Greece or Ireland which are in the EU periphery. Once again, all deviations have a temporary character since in the medium run i.e. less than eight (8) quarters, the GDP of Belgium returns back to its initial equilibrium position.

Figure A3 suggests that the GDP of Finland is significantly affected in the short run, by a shock in the Debt of Italy and Luxembourg, while it is also affected by a shock in the majority of the EU12 GDPs with the sole exception of the Greek GDP. Once again, a striking finding is that a shock in the Greek GDP or Debt does not seem to have any effect on the GDP of Finland, probably due to the fact that the two countries do not have any significant trade relationships. All deviation have a medium run character since the GDP of Finland returns back to its initial equilibrium position in less than eight quarters.

Figure A4 suggests that the GDP of France is significantly affected, in the short run, by a shock in the Debt of Austria, Belgium, Finland, Greece, Italy, Luxembourg and Netherlands, while it is also affected by a shock in the majority of the EU12 GDPs with the exception of Germany, Greece, Luxembourg and Portugal GDPs. The wide connectivity of the French GDP with the rest of the EU12 economies could be attributed to French Banking sector that has penetrated in the EU12 economy, which in consistent among others with the work of Dees and Zorell (2012) who found increased business cycles synchronization among EU countries that shared significant trade and financial linkages. However, all deviations have temporary character since in the medium run the GDP of France returns back to its initial equilibrium position.

According to Figure A5, the GDP of Germany, which is the dominant economy in our SBGVAR model, is significantly affected in the short run, i.e. less than four (4) quarters, by a shock in the Debts of Belgium, Finland and Italy while it is not affected by the GDPs of Greece, Luxembourg and Portugal. An interesting finding is that the German economy is not dependent on the economies of both Greece and Portugal who are the first victims of the ongoing recession, whereas its GDP is affected by a shock in the Italian Debt probably due to their very strong trade relationships and is evidence of limited synchronization of the EMU periphery to the core countries, including a noted clustering into small and large economies (see among others Artis and Zhang 1997; and Artis et *al.* 2003). All impacts on the German GDP have a medium run character since they returns back to their initial equilibrium position in less than eight (8) quarters.

Turning to Figure A6, the Greek GDP is significantly affected, in the short run, only by a shock in the Debt of Germany and the GDPs of Belgium, Italy and Netherlands. The interconnection between the German Debt and Greek GDP could be attributed to the strong correlation between the lending spread of the two economies, since the German lending spread acts as the basis of the Greek one. On the other hand, interconnection of the Greek GDP with those of Netherlands, Italy and Belgium is, in general terms, in line with the work, among others, o Gouveia and Correia (2008) and Camacho et *al.* (2006). Once again, all effects have a medium run character since the Greek GDP returns back to its initial equilibrium position in less than 2 years i.e. eight (8) quarters.

Figure A7 suggests that the GDP of Ireland is significantly affected, in the short run, by a shock in the Debt of Germany and the GDPs of Finland, France and Italy. Once again, the effect of the German Debt on Irish GDP could be attributed to the lending spreads, as in the case of Greece. All deviations have a medium run character since in less than eight (8) quarters the Irish GDP returns back to its initial equilibrium position.

According to Figure A8, the GDP of Italy is significantly affected, in the short run, i.e. in less than four (4) quarters by a shock in the Debts of both the Greek and the German economies, and the GDPs of Belgium, France, Ireland, Luxembourg, Portugal and Spain. The relationship between the Italian GDP and the Greek Debt could be attributed to the fact that both economies suffer from similar structural debt deficiencies; therefore a link between the two countries seems to be in place. On the other hand, the German Debts affects the Italian GDP since it affects its external lending rate. Again, all impacts have a medium run character since in less than eight (8) quarters the Italian GDP returns back to its initial equilibrium position.

Next, turning to the GDP of Luxembourg, in Figure A12, we witness that it is significantly affected by a shock in the Debts of Finland, France, Germany, Greece and Italy while it is also affected by the GDPs of the majority of the EU12 economies with the exception of Austria, Finland Germany, Greece and Italy. All deviations have a medium run character since in less than two (2) years the GDP of Luxembourg returns back to its initial equilibrium position.

According to Figure A9, the GDP of Netherlands is significantly affected by a shock in the majority of EU12 Debts with the exception of the Debts of Germany, Greece and Ireland, while in the same time, it is also significantly affected by all the EU12 GDPs. The connection between both the Greek and Irish debt with the GDP of Netherlands seems to be dictated by the fact that Netherlands suffers from enormous households debt which, according to macroeconomic theory, along with the government's debt act as twin deficits. In fact, there is an increasing number of studies in the literature suggesting that deterioration of public finances could result to a debt crisis (see among others Haugh et *al.* 2009, , Borgy et *al.* 2011, Ejsing and

Lemke 2011). However, all impacts have a medium run character since the GDP of Netherlands returns back to its initial equilibrium position in less than eight (8) quarters.

Figure A10 suggests that the GDP of Portugal is significantly affected in the short run, i.e. less than four (4) quarters by a shock in the Debts of Belgium, Finland, France, Ireland, Italy, and Spain while it is also affected by the majority of EU12 GDPs with the sole exception of Austria, which is in line with the work of Furceri and Karras (2007) that suggest a strong, statistically significant and negative relationship between economy size and business cycle volatility implying that smaller countries are subject to more volatile business cycles than larger ones. Nevertheless, all impacts have a medium run character since in less than eight (8) quarters the Portuguese GDP returns back to its initial equilibrium position.

Finally, according to Figure A11, the Spanish GDP is significantly affected in the short run by a shock in the Debt of Germany and the majority of GDPs of the EU12 economies with the exceptions of the Belgian and Portuguse GDPs. Again, all impacts die out in the medium run i.e. less than two (2) years, when the Spanish GDP returns back to its initial equilibrium position.

To sum up, it is worth noticing that the German economy which was found to be dominant economy in the model, significantly affects the GDPs of all the EU12 economies, either directly, in the sense that the German GDP affects the GDP of another economy, or indirectly in the sense that the German Debt affects the GDP of another economy. In this context, we witness that the Southern European economies, such as Greece, Italy and Spain that face either Debt issues or Structural issues often due to their inefficient banking system are primarily affected by the German Debt, as opposed to the rest of the economies that are affected mainly by the German GDP. This, could be attributed to the role of the German economy as the locomotive of the overall Debt sustainability of the EMU, since historical data regarding the spreads of external financing of EMU countries, clearly indicate that after the EMU formation the German economy benefited by the lowest spreads in the EMU area.

In brief, taking into consideration the GIRF analysis, we can see that they settle down relatively quickly, a fact which implies that the model is stable and is supported by the model's moduli which are less that unity In general, the GIRFs results show that the responses of all variables to the various shocks do not exhibit sizeable effects, which are, on average, equal to less than 1-1.5%. All shocks take place in the short run, i.e. less than four (4) quarters and die out in the medium run i.e. two years or eight (8) quarters becoming statistically non-significant. Nevertheless, none of these shocks has a long lasting effect since the GDPs of all countries return back to their initial equilibrium positions.[9]

6. Concluding Remarks

The main point of departure is the characterization of economic networks in terms of their degree of pervasiveness which is considered to be a measure of dominance. To this end, using the network economy described by Acemoglou et *al.* (2012) as well as on the generalization of pervasiveness, which is described in Pesaran and Yang (2016), based on Bailey et *al.* (2016), we have constructed a GVAR scheme, which is capable of perfectly characterizing the general equilibrium price equation of the network model. In this context, we expressed the EU-12 economies as a network system, and using data on the GDP and Debt of these economies we estimated the respective price equations for each economy in a general equilibrium framework. Also, we conducted further robustness analysis and examined the degree of pervasiveness of each economy, which is associate with the existence of dominant(s) entity in the GVAR model.

In this framework, the (macro)econometric model that has been developed can be used to examine the propagation of fluctuations across economies that face high debt deficits. In fact, it can be easily used for analyzing a number of transmission mechanisms, contagion effects and network interdependencies in a global, as well as domestic setting. As we know, financial institutions are increasingly vulnerable to the fluctuations in the economies in which they are exposed. Hence, the risk analyses of a financial institution's activities need to take into

[9] Similar results were obtained based on the Debt GIRFs, which are available upon request by the authors, due to space limitations.

consideration domestic as well as international economic conditions of regions that directly or even indirectly influence the institution loan's portfolio, without neglecting the dominant role of certain economies, such the German economy.

Hence, our focus has been on developing a compact and robust general equilibrium representation of the complex interactions across factors. The proposed model allows for direct dependence of the financial and macro factors on: (i) the their domestic parts and their lags, (ii) dependence of common global variables such as stocks traded and trade and (iii) certain degree of dependence of idiosyncratic shocks across regions captured via the cross-region covariances (e.g. Pesaran et al. 2004). For example, the proposed model is able to account for inter-linkages between the various debt deficits among the EMU economies. Also, the use of a regional weighting scheme with dominant economies allows for efficient use of all available data.

More specifically, in this work, using a network general equilibrium framework we studied the transmission of shocks and more specifically of the debt crisis between the EU12 economies, namely Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal and Spain after the introduction of the Euro currency. According to our findings the German economy was found to be the dominant economy in the model using, both, the δ -value of pervasiveness as well as other network theory measures and of course the eigenvalue distribution of the Input Output weight matrix. This finding is fully consistent with the literature, and the recent developments in the socio-economic situation in Europe.

Next, our work estimated the link between output and debt fluctuations in EU12 based on the global variables of trade and finance, which act as the transmission channels that have been documented in the literature as being most significant. Our results confirm the fact that the role of trade volumes and the volume of stocks traded are of great importance in the transmission of fluctuations, in accordance with Frankel and Rose (1998), Imbs (2004, 2006), Chiquiar and Ramos-Francia (2005), Calderon et *al.* (2007) and Artis and Okubo (2011). It is exactly in this line of thinking that Stock and Watson (2005, abstract), have argued that: "Had the common international shocks in the 1980s and 1990s been as large as they were in the 1960s and 1970s, G7 business cycles would have been substantially more volatile and more highly synchronized than they actually were" implying that the various transmission channels through which the different spillover effects between countries are activated, have been enormously strengthened lately because of globalization.

A main finding is that the various shocks die out in the medium run, namely in less than eight (8) quarters, i.e. 2 years, and cannot affect the EU12 economies in the long run. However, our analysis also showed that the German economy has a significant impact on the rest of the EU12 economies either directly, i.e. through its GDP or indirectly i.e. through its Debt. An interesting finding of our investigation is the fact that the Southern European economies such as Greece, Italy and Spain that face either Debt issues or structural issues, mainly because of their banking systems, are primarily affected by the German Debt, as opposed to the rest of the economies that are affected mainly by the German GDP. This, could be attributed to the role of the German economy as a locomotive of the overall Debt sustainability of the EMU who has benefited by the lowest spreads in the EMU area. Our findings are, in general terms, also consistent with the empirical literature, see among others, Bayoumi and Eichengreen (1993), Dickerson et *al.* (1998), Artis and Zhang (1998a, 1998b), Crowley and Christi (2003), Massmann and Mitchell (2004), Camacho et *al.* (2006) and Concaria and Soares (2009). See also Canzoneri, Valles, and Vinals (1996), Bayoumi and Eichengreen (1997a, 1997b) and Taylor (1995).

Undoubtedly, future and more extended research on the subject seems to be necessary focusing on additional potential transmission channels, such as foreign direct investment, or even more importantly, bank lending and monetary policy. Of course, the proposed analysis could also be extended routinely to account for additional variables, which have often proved to be relevant. Hence, the proposed approach could be routinely extended empirically to include other major economic regions such as USA, China, Russia, etc that would help further explain global imbalances.

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Appendix A.

Figure A1: GIRFs, Response of GDP Austria posterior s.d. appear as bands

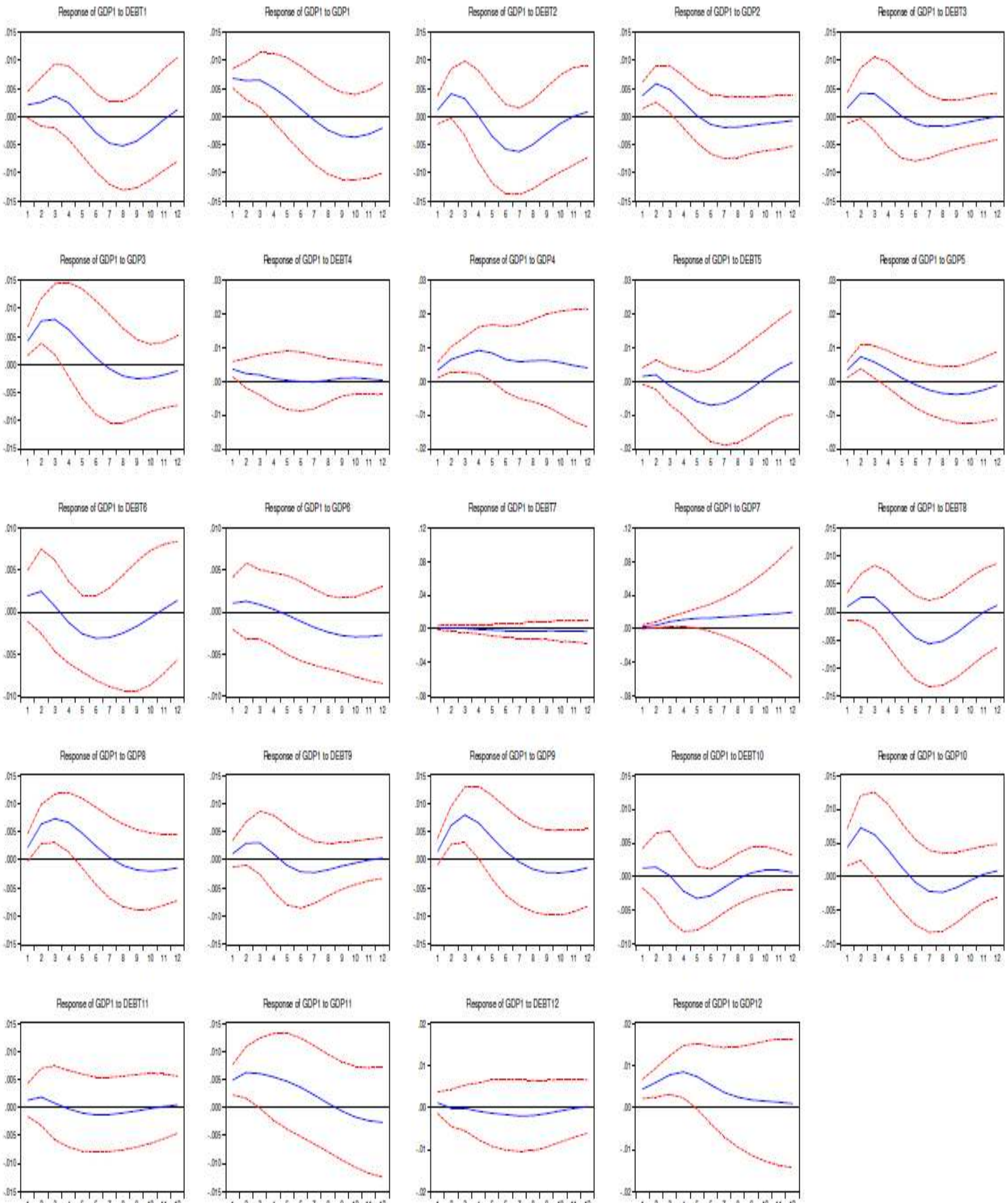

Figure A2: GIRFs, Response of GDP Belgium posterior s.d. appear as bands

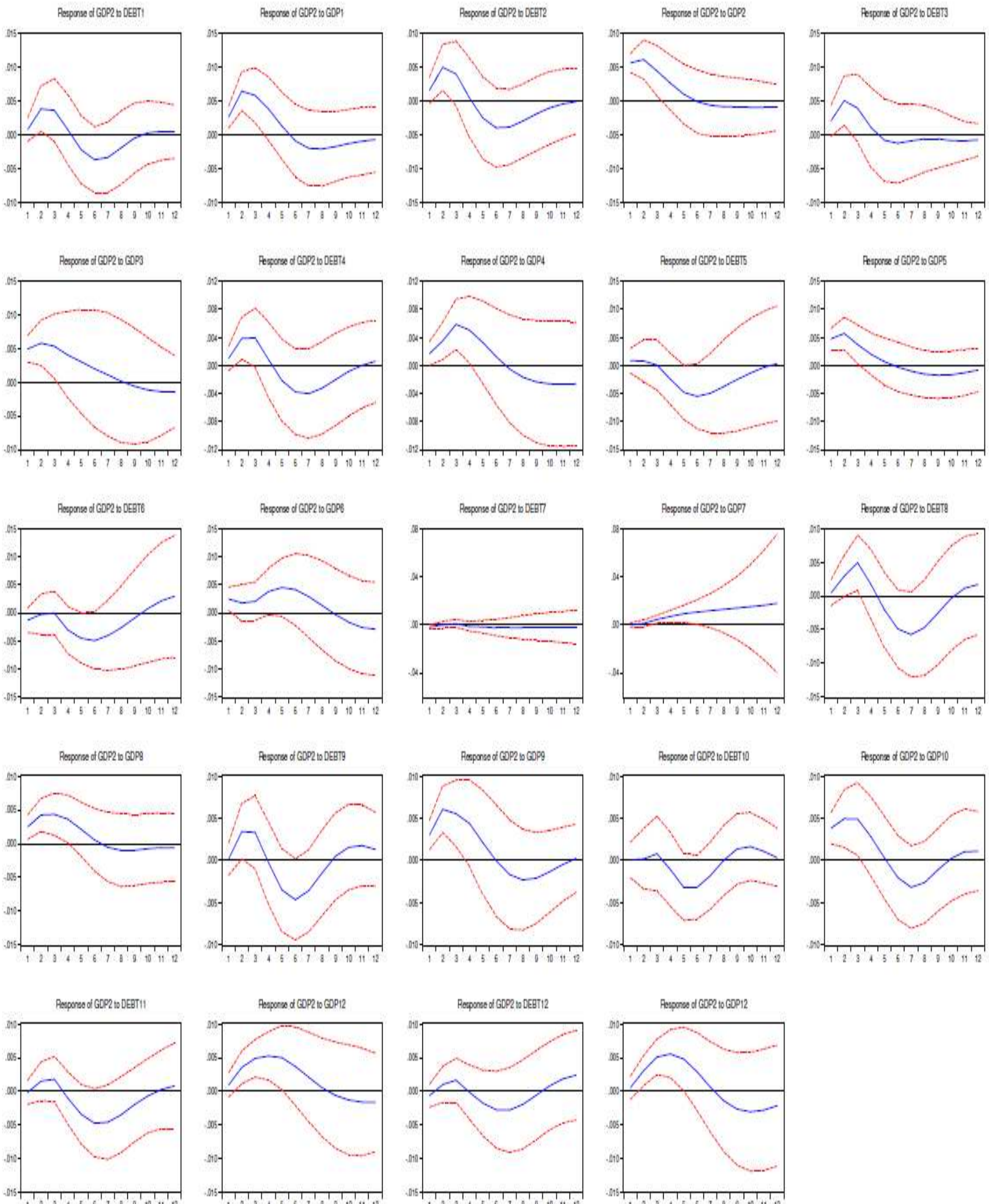

Figure A3: GIRFs, Response of GDP Finland posterior s.d. appear as bands

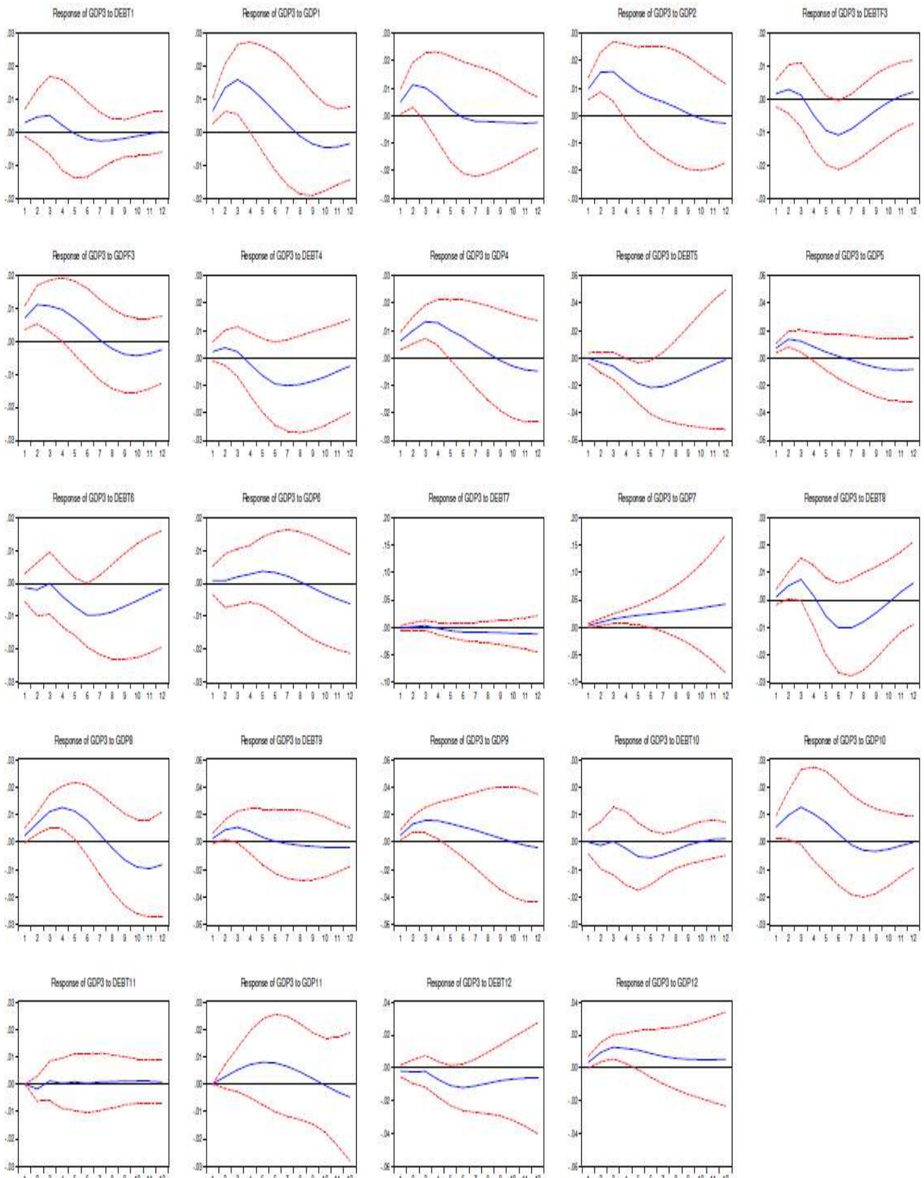

Figure A4: GIRFs, Response of GDP France posterior s.d. appear as bands

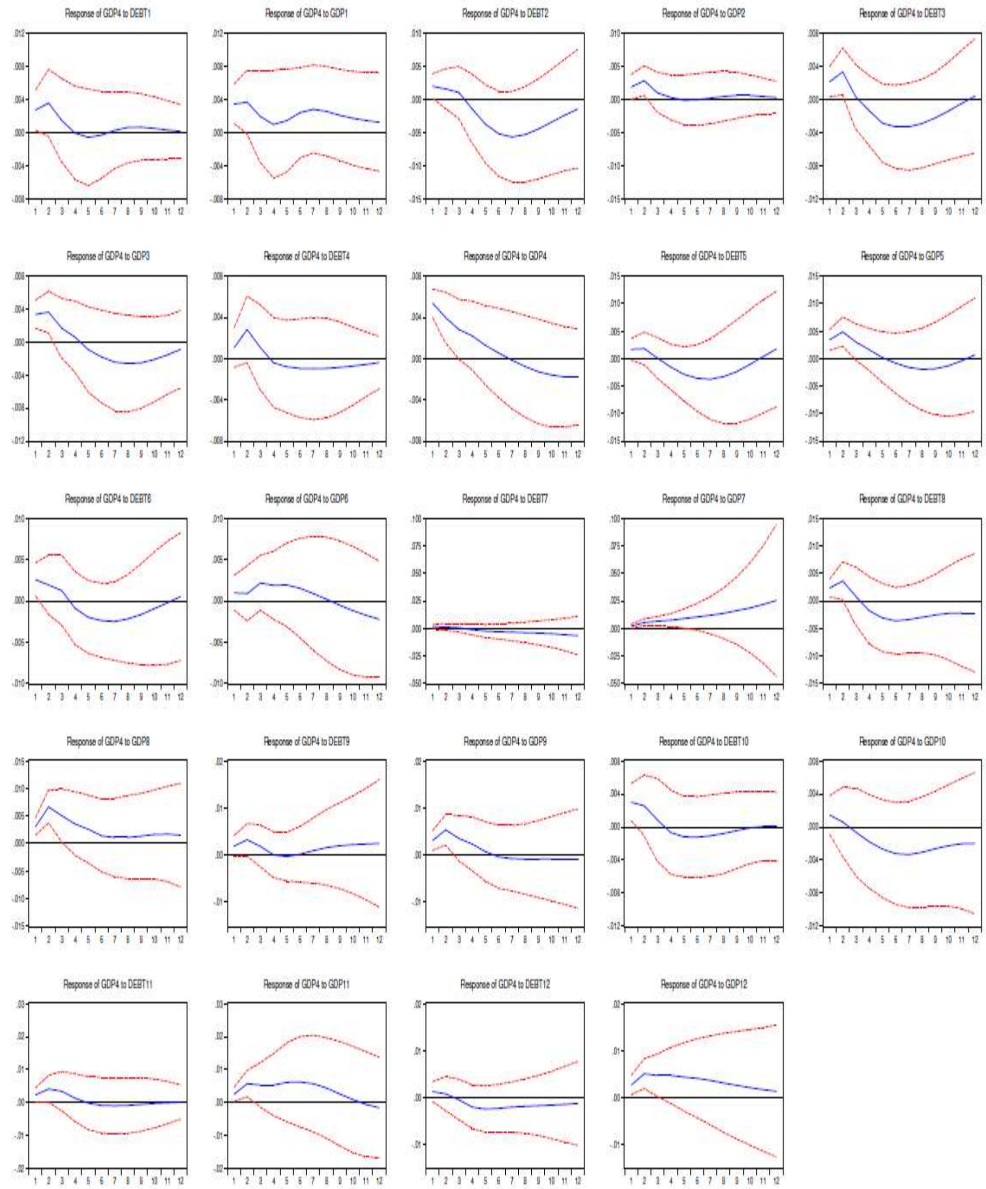

Figure A5: GIRFs, Response of GDP Germany posterior s.d. appear as bands

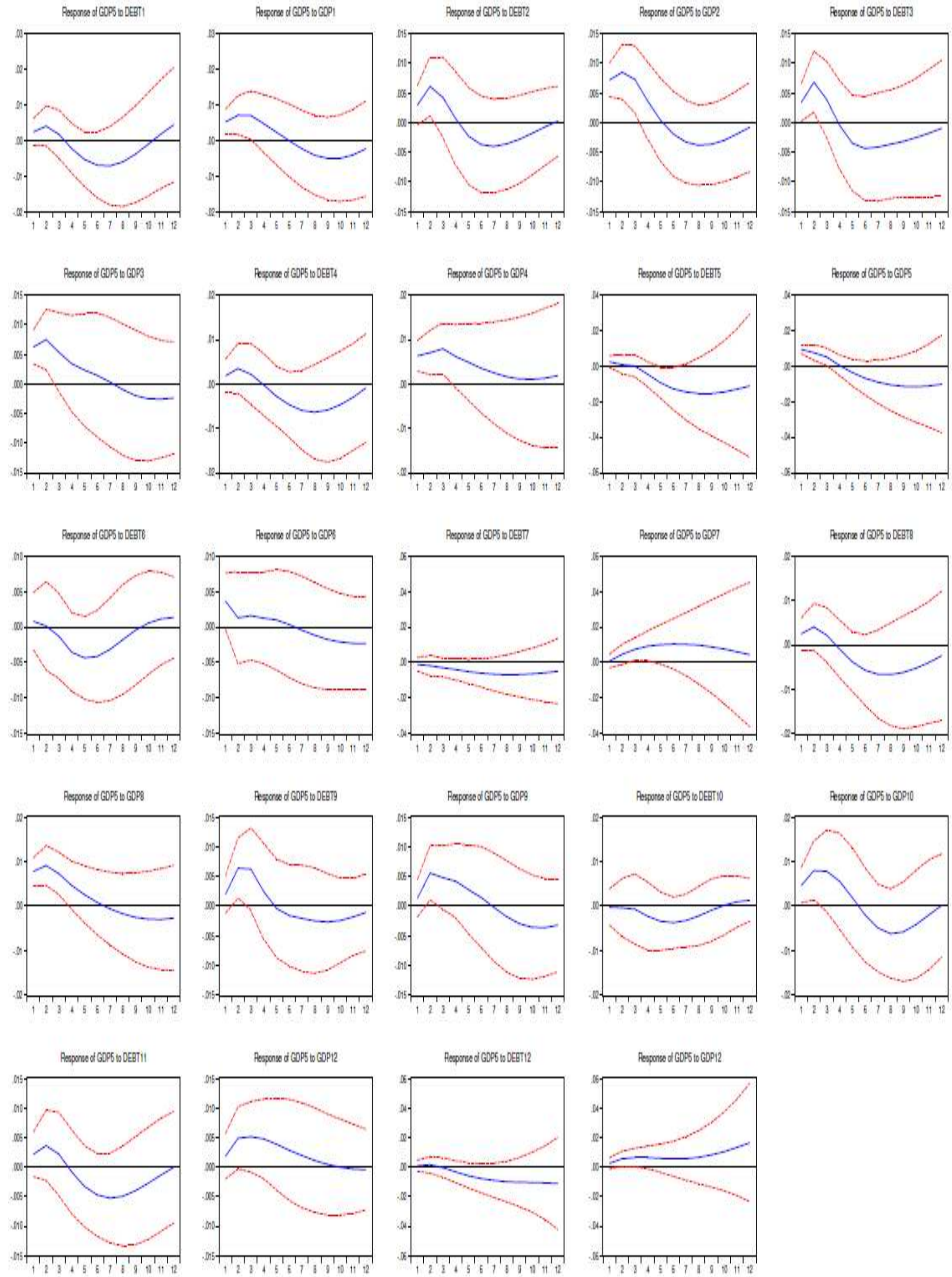

Figure A6: GIRFs, Response of GDP Greece posterior s.d. appear as bands

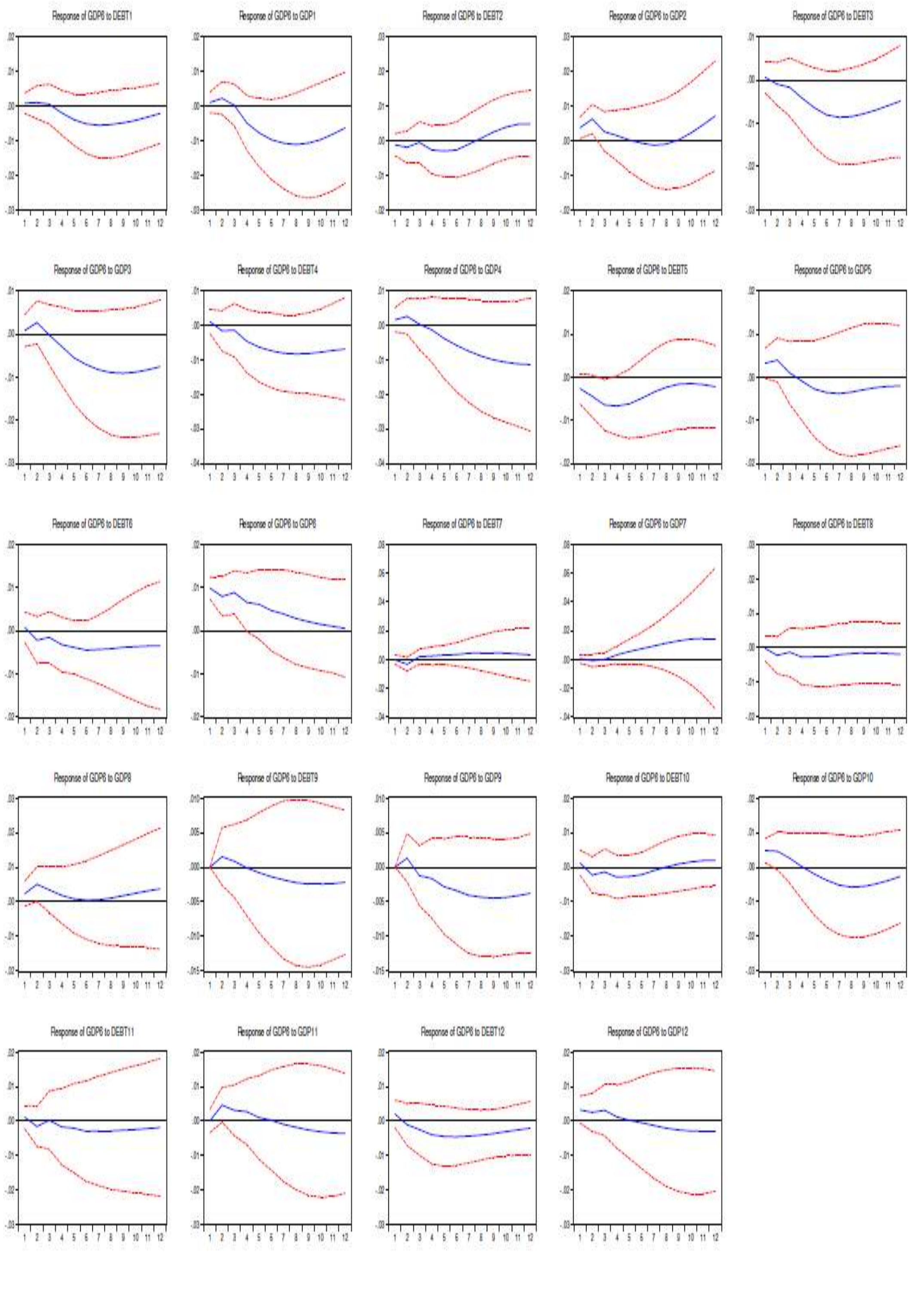

Figure A7: GIRFs, Response of GDP Ireland posterior s.d. appear as bands

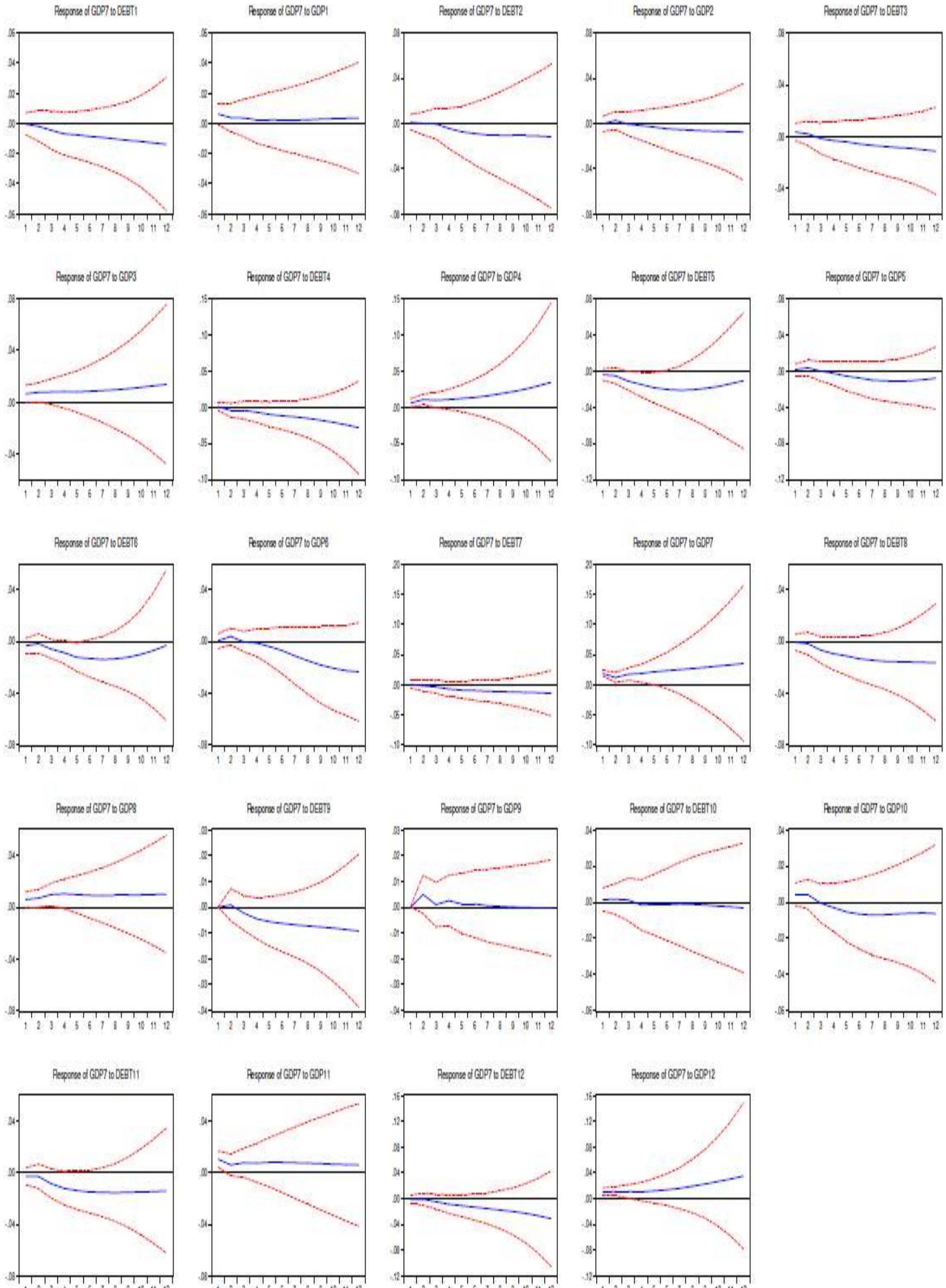

Figure A8: GIRFs, Response of GDP Italy posterior s.d. appear as bands

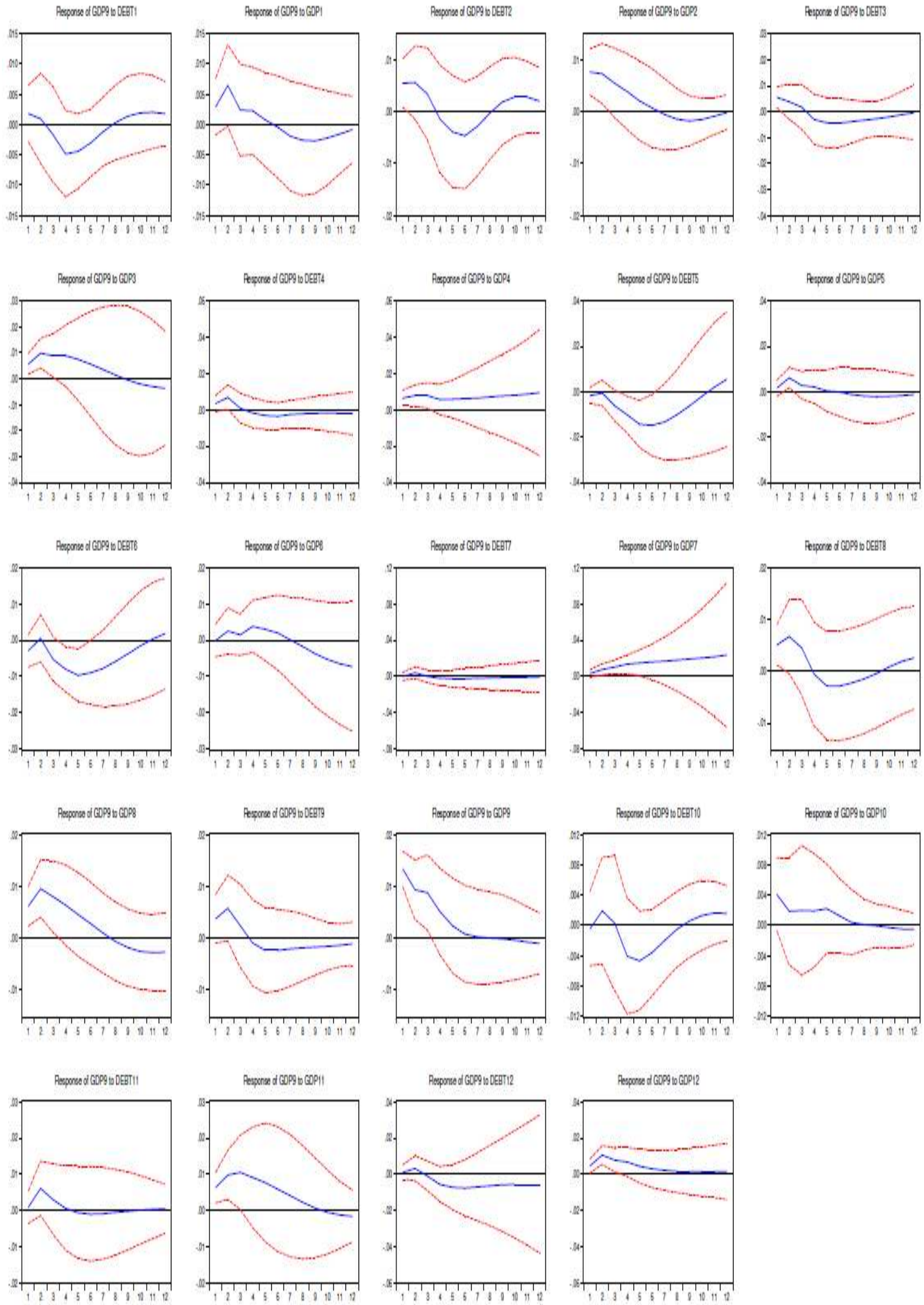

Figure A9: GIRFs, Response of GDP Luxembourg posterior s.d. appear as bands

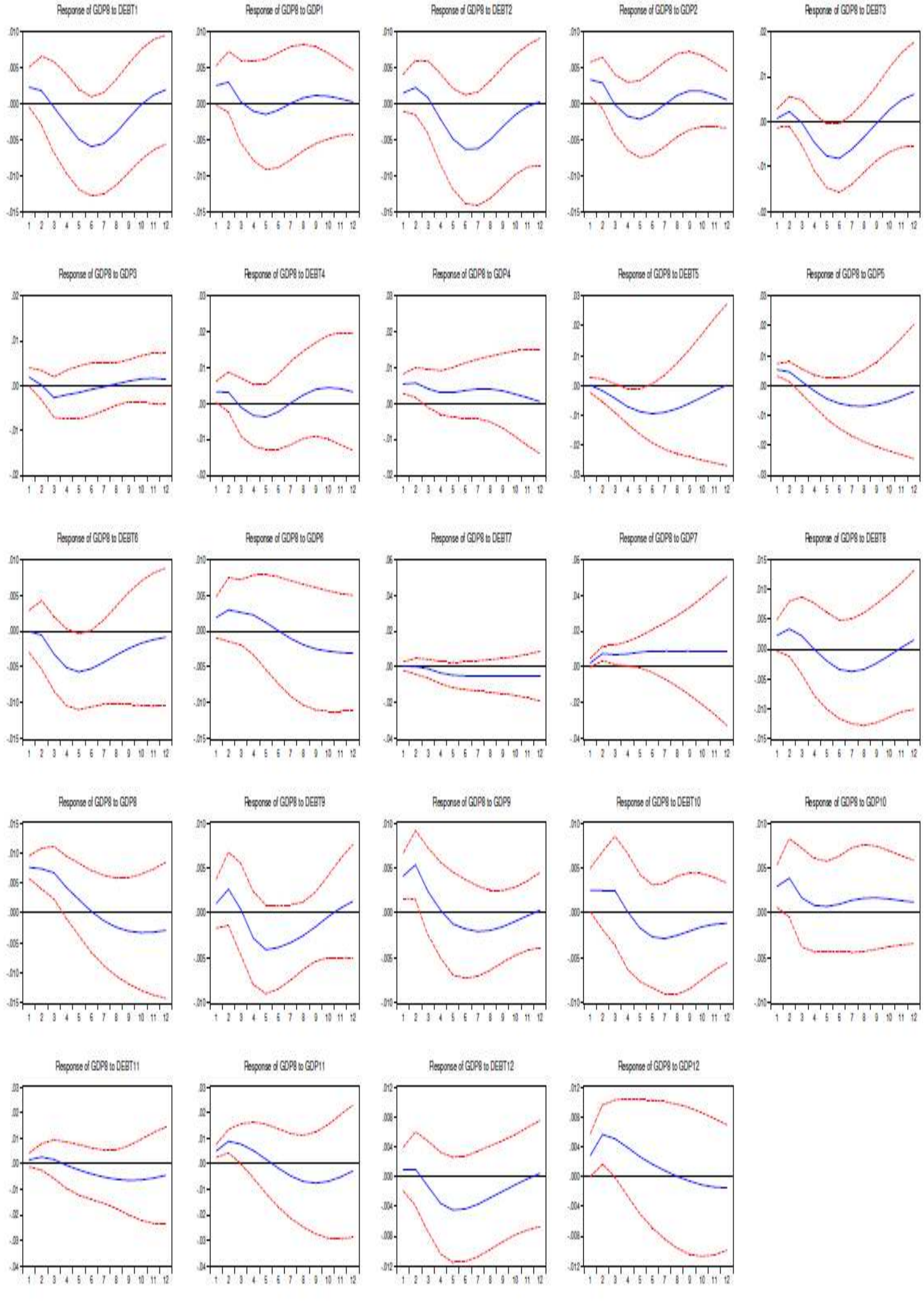

Figure A10: GIRFs, Response of GDP Netherlands posterior s.d. appear as bands

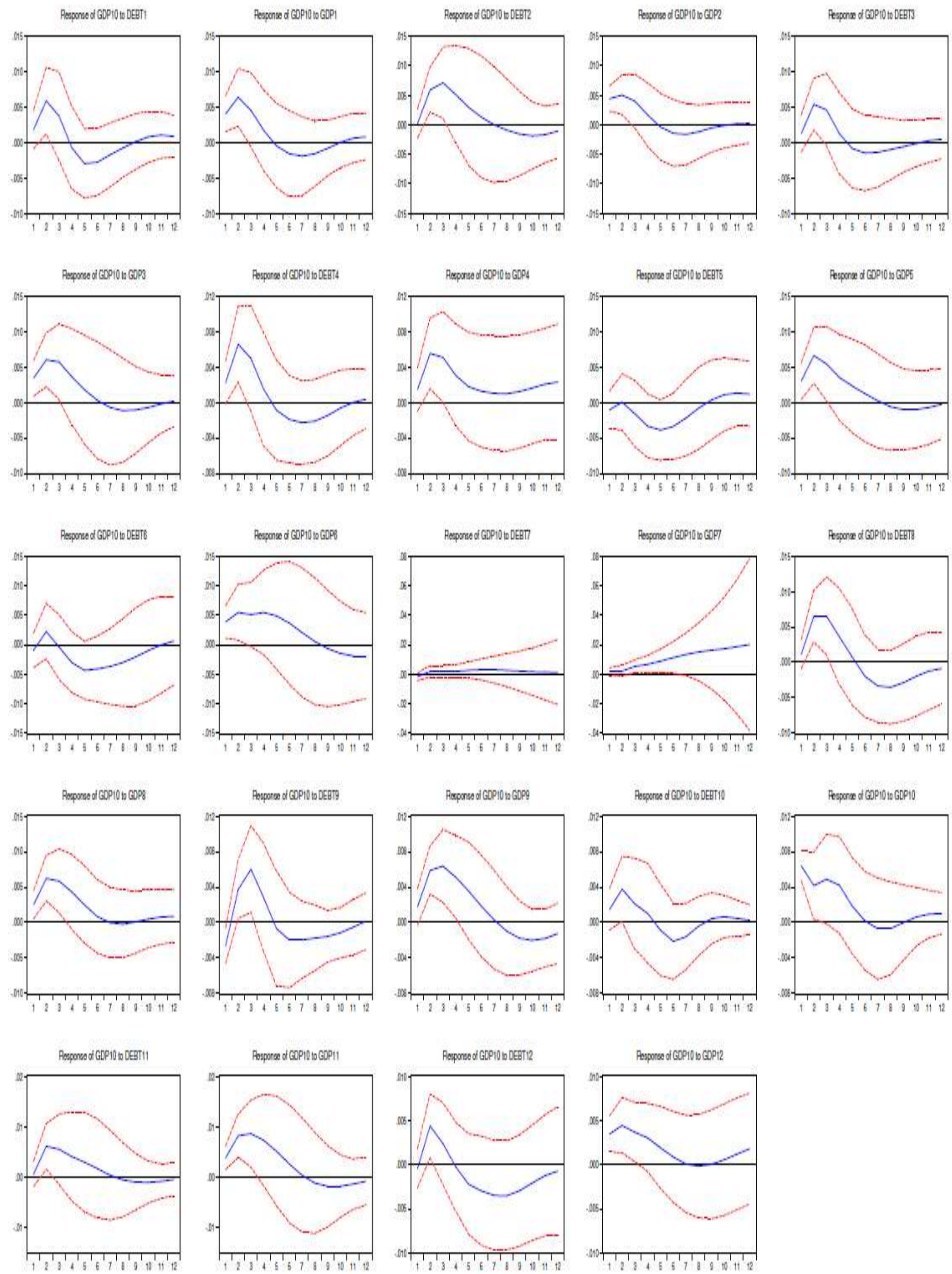

Figure A11: GIRFs, Response of GDP Portugal posterior s.d. appear as bands

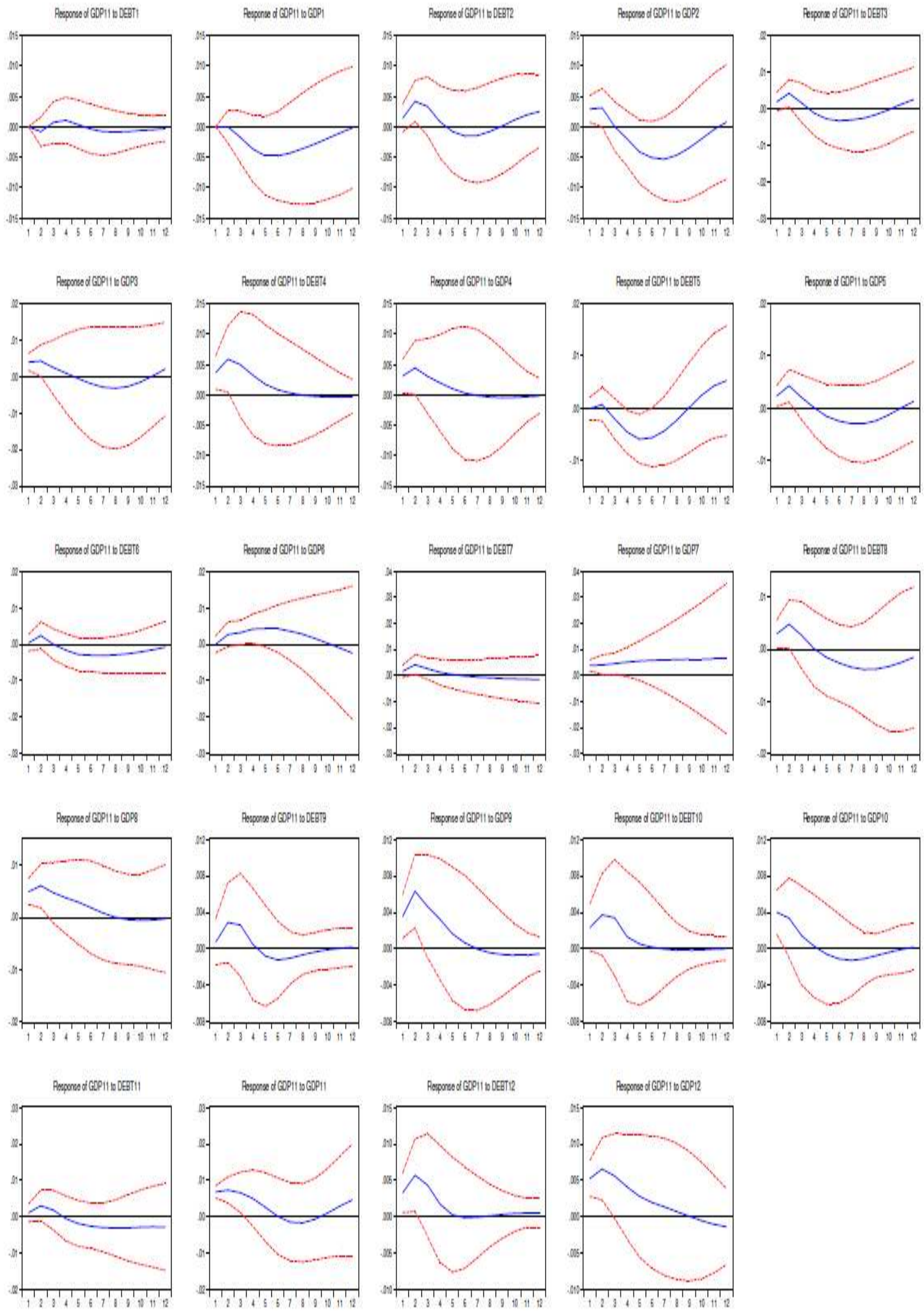

Figure A121: GIRFs, Response of GDP Spain posterior s.d. appear as bands