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TRANSMISSION OF FINANCIAL SHOCKS TO AND FROM THE EURO AREA: A GVAR APPROACH

Master's Thesis

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Declaration of Authorship

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Abstract

This thesis studies the international transmission of financial shocks using the Global Vector Auto-Regression (GVAR) approach, with an emphasis being placed on the euro area. Unlike previous research, the thesis simulates financial shocks through the ECB's Composite Indicator of Systemic Stress (CISS) in order to express the shock more directly. Additionally, the shadow rates estimates are included in the model to account for the presence of unconventional negative interest rates that have marked the economic developments of the last 15 years. The results generally suggest significant international consequences of the shocks. This is so also in the case of the simulated financial shock originating in the euro area, which is shown as potentially even more damaging than the US shock. Numerous other interesting results regarding the spread of the shocks are derived from the model. It is also found that shadow rates can affect the results to an extent, most notably perhaps in the case of the short-term interest rates in the euro area.

JEL Classification	E17, F37, F47
Keywords	GVAR, financial shocks, financial stress, international economic linkages, euro area
Title	Transmission of Financial Shocks to and from the Euro Area: A GVAR Approach

Abstrakt

Táto práca skúma medzinárodné šírenie finančných šokov používajúc prístup Global Vector Auto-Regression (GVAR), pričom dôraz je kladený na Eurozónu. Na rozdiel od predošlého výskumu, práca simuluje finančné šoky cez Composite Indicator of Systemic Stress (CISS), aby bol šok vyjadrený priamejšie. Okrem toho sú v modeli zahrnuté odhady tieňových úrokových mier, aby bola zaznamená prítomnosť nekonvenčných záporných hodnôt úrokových mier, ktoré poznačili ekonomický vývoj posledných 15 rokov. Výsledky vo všeobecnosti naznačujú významné medzinárodné dopady šokov. Je to tak aj v prípade simulovaného finančného šoku z Eurozóny, ktorý je modelom ukázaný ako potenciálne ešte ničivejší než šok z USA. Z modelu sú získané viaceré ďalšie zaujímavé výsledky týkajúce sa šírenia šokov. Je takisto pozorované, že tieňové úrokové miery môžu mať určitý vplyv na výsledky, najvýznačnejšie zrejme v prípade krátkodobých úrokových mier v Eurozóne.

JEL Classification E17, F37, F47

Keywords GVAR, finančné šoky, finančný stres, medzinárodné ekonomické väzby, Eurozóna

Title Transmisia finančných šokov do a z Eurozóny: GVAR prístup

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Contents

1 Introduction

To gain a better perspective on the causes and effects of financial crises, it is undoubtedly essential to further our understanding of international financial linkages and the vulnerability they may present for the global financial system. Research in this area has surely gained much relevance in the aftermath of the 2007 financial crisis, however, earlier crises, such as the 1997 Asian crisis, may have already demonstrated the importance of studying international spillovers of financial shocks. The consequences of the global financial crisis still being one of the major topics of the scholarly debate, particularly perhaps in relation to the global economy's response to more recent large-scale crises such as the COVID pandemic, and with regard to potential threats and fragilities in global finance looking ahead, the topic of international transmission of financial shocks still appears highly relevant. While the research may, in this case, tend to put the spotlight on the United States and its financial markets, focusing more on the smaller but still largely influential economy of the European single-currency area may be interesting as well, especially remembering the dire consequences of the 2007 crisis originating in the US for the euro area, where it triggered a sovereign debt crisis, and considering the ensuing era of unconventional monetary policies, which were practiced in the currency union even in the most recent years.

Vector Auto-Regression (VAR) models present a standard econometric tool used in empirical research of relations between different macroeconomic variables. Its applications are, however, largely limited to investigating how various factors influence each other within a single national economy, not allowing it hence to properly capture international economic linkages, which are naturally massively important for our understanding of the global economy. Global Vector Auto-Regression (GVAR) models, first proposed by Pesaran et al. (2004)

and later enhanced by Dees, di Mauro, Pesaran, and Smith (2007), extend the traditional VAR modeling framework to create a computationally feasible way of estimating a large system of several smaller VAR models. This makes it possible to investigate relations in a large panel consisting of many time series for several countries and variables in a single complex model.

This thesis uses a GVAR model that is mostly similar in its form to the conventionally followed example of Dees, Mauro, Pesaran, and Smith (2007). While the most common way of covering financial markets in the model may be through the equity prices data, the thesis, inspired by Dovern and van Roye (2013), chooses a different more direct approach based on financial stress indexes (FSI). Whereas in the last-mentioned work, a custom FSI variable is constructed, the model of the thesis includes the Composite Indicator of System Stress (CISS) – a direct measure of financial stress levels provided by the ECB. This indicator has already been included in a standard VAR model for the euro area by Kremer (2016). We try here to incorporate the CISS values for the euro area, the US, and the UK in a GVAR model. Crucially, these indexes are used as origins of shocks in our financial shock simulations.

The thesis tries to focus particularly on the euro area, including it as a single economy in the model, with the aggregates of the data for several core economies of the currency union being used. An emphasis is given on discussing the results of the scenario of a financial shock originating in the euro area. Given the aims of the thesis, a comparison of this scenario with the case of a shock from the US, i.e., from the most important economy and financial market, shall be crucial together also with a discussion of the consequences of a shock from the US on the euro area. Linkages besides the transatlantic transmission channel should be of great interest to us when evaluating the results as well – particularly interesting should be assessing whether the euro shock would be predicted to have consequences broadly across the world, even in regions that do not seem naturally as interlinked with the euro area as the US. Despite the focus on the European currency union, the results may naturally bring us also to results relevant for other countries, (mainly for the other two countries that we have the CISS index available for, the US and the UK) or for international financial spillovers in general. Besides the euro area, our sample covers 25 other economies (both advanced and developing) and contains quarterly data from the 1999-2023 period, that is, it includes also very recent data.

A source of some novelty in the thesis approach should also be an attempt to include shadow rates into the model. The concept of shadow rates has gained attention due to the unconventional monetary policies of the post-crisis era, which have pushed the interest rates practically below zero. Even though the standard nominal rates data remain around zero during the years of extremely low interest rates, going at most slightly below zero, the shadow rates estimate by Wu and Xia (2016) can go well below the zero bound. The rates are available during our sample period for the same three countries for which the CISS indices are – that is the euro area, the US, and the UK. Given our focus on the euro area, the inclusion of these shadow rates may seem potentially important, as in the case of the ECB, the negative shadow rates estimates have been a reality for a particularly long time, interestingly especially also recently during the pandemic. The inclusion of the rates in the sample with the short-term nominal rates data may not be straightforward and the way it has been done in our model could be a source of some imperfections or distortions, nevertheless, having shadow rates included may give us some additional interesting insight. A comparison of our model with shadow rates with the model version not using them could also provide us with some particularly notable results.

The rest of the thesis is divided into four main sections. The next section provides a brief overview of the literature that may be relevant given the topic. The following section then discusses extensively the methodology of the thesis model. First, a theoretical summary of the GVAR approach is provided, following largely Chudik and Pesaran (2016). This is essential so that the technical details of the method deployed in the thesis are explained at least to an extent, nonetheless, the knowledge of the mathematical foundations of the models should not be necessary to understand the empirical application of the model as done in the thesis. Following this general theoretical part, the details of our model specifically are provided. This includes the discussion of the model's main diversions from the baseline GVAR model, i.e., the FSI variables and the inclusion of shadow rates, the description of the sample, and additional notes on the specification. This rather extensive section is followed by another larger section discussing the results. We are interested mainly in the impulse response functions (IRFs) covering the projected responses to our simulated financial shocks. The graphs covering the IRFs are provided directly in the results section, other parts of the output are included as appendices. The results section describes the projections of the model in detail and with regard to various variables, scenarios, and countries. The final section briefly summarizes the most important conclusions of the thesis.

2 Literature Overview

In the first part of the literature overview, works that have been important in the development of the GVAR modeling as such are mentioned. The second part then summarizes numerous papers that apply the method for research topics similar to that of this thesis.

The GVAR model was introduced originally by Pesaran et al. (2004). Vector Autoregression (VAR) models, which allow an empirical examination of relations between variables within one economy (system), had already been in use long before. It is, however, not possible to deploy a simple VAR model to study the global economy, a large system of many interrelated economies. Using the VAR framework in a multinational setting is a challenging task due to the great computational complexity that necessarily arises when several economies each with multiple variables are being studied. Pesaran et al. (2004) present a computationally feasible way of extending the basic VAR methodology so that numerous economies can be included. This method is not limited only to macroeconomic applications with several countries and can be used essentially to study any system composed of several smaller subsystems, each with several local variables. Applications to the global economy are nonetheless the most common and intuitive way of using the model, hence the name Global Vector Autoregression (GVAR) model.

While Pesaran et al. (2004) provide theoretical foundations for the model, they assume that foreign variables, i. e, variables of other countries in the local submodel for a particular country, can be treated as weakly exogeneous without providing proof for this assumption. A theoretical justification was first presented by Dees, di Mauro, Pesaran, and Smith (2007), who essentially upgraded the original model in their paper. This paper provides in a sense a definite version of the GVAR model and practical applications can be said to be built on this paper rather than the original one by Pesaran et al. (2004). The proof of the weak exogeneity assumption was later developed further by Chudik and Pesaran (2011, 2015). I believe it is not important to explain in more detail the mathematical validation of the assumption (and hence of the whole model) here, as it is not necessary for a practical application such as the one in this thesis, however, it is important to be aware of these works, thanks to which the model can now be considered as having a truly rigorous theoretical foundation.

The paper by Chudik and Smith (2013) studying the importance of the US economy in the global economy may also be worth mentioning. In this study, an extended version of the GVAR model is developed, such that the US is set as the dominant economy. The results support this notion. This can, of course, be deemed an empirical conclusion, however, it has also theoretical implications for the GVAR modeling. If the US is assumed to have a significantly dominant role in the global economy, the GVAR model would some require potentially major modifications to account for the dominancy of the US to be considered truly appropriate and theoretically sound. Changing the model in this way may pose some difficulties and have some disadvantages for the model. We should remain aware of the possibility of the US dominance scenario when evaluating the results, since it may render them potentially less accurate and trustworthy, although, at the same time, it should be noted we do make certain changes when specifying the US submodel also in our case.

The use of the model for empirical research has been made much easier thanks to the GVAR Toolbox by Smith and Galesi (2014). The first version of the Toolbox, sponsored by the ECB, was released already in 2010. For the purposes of this thesis, the current 2.0 version from 2014 is used. This Toolbox provides an easily runnable package for Matlab that allows running this relatively highly complex model and getting the output in a very simple way. The GVAR Toolbox also includes a detailed user guide, which further explains many issues regarding the specification and correct deployment of the model. The data collection process for the model has also been much simplified thanks to the GVAR dataset by Mohaddes and Raissi (2024). Originally released in 2006, the dataset has been updated several times. The latest update that extends the sample till the third quarter of 2023 happened fortunately just as this thesis has been worked on.

Chudik and Pesaran (2016) provide an extensive overview of the GVAR modeling. They explain the theory behind the model and summarize the history of its development and applications, naming various notable papers using the method. This paper is hence a particularly useful reference point for finding more about the GVAR and academic research built around it. The explanation of the model's mechanism by Chudik and Pesaran (2016) is followed in this thesis in the part that gives a brief theoretical introduction to the model.

Given the topic and aims of the thesis, the already-mentioned work by Dees, di Mauro, Pesaran, and Smith (2007) may be the most important work using the GVAR model to mention. This paper (co-authored by Pesaran himself), which, as has already been said, has been crucial in the development of the model is centered around essentially the same application of the model as the thesis, with the focus of the empirical part being also on the euro area as a single economy, although a large portion is still actually dedicated to updating the US model. As far as the results regarding the euro area go, a rapid transatlantic transmission of financial shocks as well as a potential for amplification during this transmission is shown, while the effect of oil shocks is suggested to be much less profound and the effect of monetary shocks from the US is not statistically significant. Crucially, the sample of the study ends in 2003, hence not covering even the Global financial crisis. With all the unprecedented events of the following two decades, their addition to the modeling may now naturally appear quite necessary. It must also be noted that this paper, just as numerous mentioned further in the section, uses a different way of proxying financial shocks than the thesis – the financial shock in the US, whose effect on the euro area is measured, is simulated through the inclusion of the US equity prices.

Sgherri and Galesi (2009) deploy the GVAR model to study the spread of financial shocks from the United States across various EU-integrated and integrating countries. The variables used to cover the financial sector are concerned with interbank rates, equity prices, and credit for corporations (all in real terms). They add to the modeling's complexity by adjusting it for the financial weights, which account for foreign variables, i.e., they attempt to capture the international financial flows. Their results suggest that financial shocks spread quickly across the Atlantic and can be even amplified during the transmission. They also conclude more generally that the short-term spread seems to be working primarily through asset prices.

Castrén, Dées, and Zaher (2010) apply the GVAR model to the euro area as well, albeit investigating a different research question. They examine how the likelihoods of defaults in the euro area's corporate sector respond to various shocks using expected default frequencies (EDFs). What may be particularly interesting for us in their conclusions is that shocks to equity prices, i.e., financial shocks, are also among those that are found to have the largest effects on corporate defaults. Chen, Gray, N'Diaye, Oura, and Tamirisa (2010) study the transmission of corporate and banking distress. Just like the last-mentioned study, they also use EDFs, differentiating between financial and non-financial companies. The results generally support the idea of fast and significant macroeconomic spillovers both within a country and internationally. Notably, the study concludes that in advanced economies banking distress poses potentially a larger threat than corporate distress.

Chudik and Fratzscher (2011) focus on the international spread of the 2007 financial crisis from the US, again using the GVAR framework. Their sample includes numerous larger developed or emerging economies from across the globe – as the thesis, they too decide to treat the whole euro area as a single economy. The study stresses its effort to distinguish through which channels did the contagion spread and hence, just as the previously mentioned one, includes multiple variables to cover the financial shocks. Namely, the VIX index and the TED spread are used to capture the financial market risk and liquidity pressures, respectively. The findings support the relevance of this differentiation, as it is shown that while the liquidity channel played a crucial role in the transmission to the advanced economies, the changes in the risk appetite were relatively more important for the transmission to the emerging economies.

Financial spillovers in a broader sense are examined by Eickmeier and Ng (2011), who focus on the spread of credit supply shocks in the US, the euro area, and Japan, using a longer sample from a variety of advanced and emerging global economies. To capture the credit supply, the data on real private credit and corporate bond spreads are added to other standard macroeconomic variables. The paper also tries various possibilities of assigning trade and/or financial weights to account for foreign variables. The conclusions again support the existence of a significant transmission channel from the US – although the effect on the euro area is estimated to be lower than on Japan, it can still be as large as the effect on the US itself. Even though the shocks in the euro area or Japan do not seem to be as globally important, they are still shown as having international significance, particularly for the European case.

Sun, Heinz, and Ho (2013) deploy the GVAR to study economic linkages in

Europe. They hence study the euro area as well as other European regions and economies. In ascribing weights in the model, they use besides trade weights also financial weights – in this regard their model differs from most other GVAR applications, including the model in this thesis, where only trade weights are used. The study finds significant co-movements between GDP growth rates and interest rates within Europe, finding the euro area to be generally the most important influence on economic developments in Europe.

While the studies on similar topics tend to be US-centric in the sense that they typically set the American economy as the origin of the simulated shock, there are still few papers centered more around Europe. Backé, Feldkircher, and Slačík (2013) use the GVAR model to study the transmission of a shock in the euro area to central, eastern, and southeastern Europe, trying to differentiate between countries based on whether the shock spreads primarily through the trade channel or the financial channel. Their methodology is based on expressing financial interlinkages between the different pairs of countries of the dataset and incorporating matrixes with this information into the model. Menon and Ng (2013) look at the potential spread of the financial shocks from the euro area in Southeast Asia, motivated largely by the aftermath of the financial crisis in Europe. This study may be particularly interesting given the location receiving the shock, which may not seem to be as obviously interlinked with the euro area as for example the CESEE region. The results conclude that a shock from the euro area would indeed have the potential to considerably affect Southeast Asia, which may perhaps be seen as further supporting the relevance of more euro-centric research. Menon and Ng (2013) also use conventional financial variables concerning interbank rates, lending, and equity prices when constructing their GVAR model.

In contrast with the above-mentioned studies, which use various financial proxies, Dovern and Van Roye (2013, 2014) put the focus on financial stress and proceed in their work by using a single stress indicator. Adding to the previous research of the linkage between financial stress and economic activity, it is their primary aim to analyze this relation on an international scale through the GVAR model. In the paper, they first themselves build a monthly financial stress index (FSI) via a dynamic approximate factor model. The deployment of the GVAR then shows that a financial shock in the US translates into a significant economic slowdown internationally, while an economic slowdown in the US negatively affects the financial stress levels internationally, although not as much as to trigger a financial crisis.

In the thesis, the approach with financial stress index is also used, however, instead of a self-constructed index, the indicators from the ECB are selected, as they now provide samples long enough for the purposes of a GVAR examination, and, given their institutional sources, we may expect them to be as precise measures of financial stress as possible. Financial stress may appear as a highly interesting variable to explore in the GVAR framework for numerous reasons. As Dovern and van Roye (2013) note, the cross-country correlations in the financial stress index vary considerably depending on factors such as the country's openness or the presence of a crisis – perhaps most importantly, in times of a crisis, the correlations tend to increase. The sample from the last decades provides a time series that covers, besides the global financial crisis, crucially also a rather long period of unconventional and extremely loose monetary policies after the crisis, which this older research could not examine.

Kremer (2016) tries to include the financial stress index in a standard VAR model for the euro area. Crucially, the CISS index provided by the ECB, which is used in this thesis, is also used in this research as the indicator of financial stress. The conclusion suggests that the index significantly contributes to the macroeconomic developments in the euro area and influences even the monetary policy. While it is found that unconventional monetary policy may react directly to changes in financial stress, interest rates seem to react rather indirectly through the impact of financial stress on GDP. Importantly, the significance of the CISS in the model is found to be robust to the inclusion of various control variables. This conclusion may hence appear as greatly supportive of the idea of adding the index to models that conventionally do not use it, in our case the GVAR model. Although the CISS index is not available across the countries in our sample, its inclusion in the GVAR model may still be particularly interesting as we are in the thesis focused on the international transmission of financial shocks and can use the index itself as the source of the shock in our simulations.

Many more interesting applications of the GVAR model could be named. Again, we may refer here to an extensive overview of these works provided by Chudik and Pesaran (2016). I hope I have managed to highlight those empirical applications that are important to mention given the topic of the thesis. As can be seen from this literature overview, topics linked to international spillovers of financial or other shocks are relatively often tackled by academic research. The shock simulation through an indicator of financial stress in the GVAR framework as done in this thesis has nonetheless not yet been done, and past literature focused on the FSIs might seem encouraging in this regard, as these indexes could potentially improve the shock simulations, or at least simply provide something novel for the model.

3 Methodology

The research in the thesis is centered around applying the Global Vector Autoregression (GVAR) modeling, developed originally by Pesaran et al. (2004). The methodology section is divided into several subsections - the first one provides a brief theoretical overview of the GVAR models (in general) following Chudik and Pesaran (2016), the following ones explains in detail the variables and data used in this application, and the last one contains some further notes regarding the model's specification.

3.1 Theoretical Framework

Vector Autoregression (VAR) models provide a statistical framework for examining how different time series variables affect each other. Baseline VAR models, however, allow typically only for a single system to be studied - for macroeconomic applications, this typically means choosing just one nation's economy. Global Vector Autoregression (GVAR) developed by Pesaran et al. (2004) extends the VAR method so that a large system composed of several smaller ones each with its local variables can be modelled in a computationally feasible way. It hence makes larger-scale international applications of VAR possible.

Although it may not be necessary to properly understand the theoretical foundations of the GVAR model in order to apply it, a short overview of how the model functions is provided below. This explanation closely follows the model's description from a summary work on GVAR models by Chudik and Pesaran (2016).

In the GVAR model, each country is described by an individual VARX model. VARX allows for choosing whether a variable is endogenous or weakly exogenous in the model. Crucially, we can set variables that are endogenous in one country's local model to enter the local model of another country. We can also add global variables, which have the same values at each time point for all the countries in the system. For technical background of VARX models with weakly exogenous regressors, we may refer to the foundational works in this regard by Harbo et al. (1998) and Pesaran, Shin, and Smith (2000).

We study N countries, each with k_i variables specific to it. There are hence $k = \sum_{i=1}^{N} k_i$ variables altogether. All the values of variables specific to a country i at a certain time t then form a $k_i \times 1$ vector, which can be denoted $x_i t$, while the $k \times 1$vector containing all the variables can be denoted $x_t = (x_{1t}^{'}, ..., x_{Nt}^{'})$.

An important component of the GVAR model is denoted as the "star" variables. Variables with the star refer here to foreign values of given variables. They are different for each country, as their calculation utilizes, besides the vector of all variables $x_i t$, also the matrix of country-specific weights $\tilde{\mathbf{W}}_i$. These weights could be set in different ways. We may manually change them if it is deemed necessary, Nonetheless, the default way of constructing the weight matrix is through the data on trade flows between the countries. This approach is also followed in our case - I have simply used the flows data provided by Mohaddes and Raissi (2024) as the weight matrix.

Using the weight matrix, the foreign or star variables are calculated in the following way:

$$x_{it}^{*} = \tilde{\mathbf{W}}_i^{'} z_t \tag{1}$$

The crucial assumption that makes the whole process of GVAR modeling theoretically valid, is that the foreign variables are weakly exogenous in each country's domestic submodel. In the end, the country-specific variables $x_i t$ are described in the model as follows:

$$x_i t = \sum_{\ell=1}^{p_i} \Phi_{i\ell} \mathbf{x}_{i,t-\ell} + \Lambda_{i0} \mathbf{x}_{it}^{*} + \sum_{\ell=1}^{q_i} \Lambda_{i\ell} \mathbf{x}_{i,t-\ell}^{*} + \epsilon_{it} \tag{2}$$

$\Phi_{i\ell}$ and $\Lambda_{i\ell}$ are vectors of unknown parameters, the former having size $k_i \times k_i$ and the latter $k_i \times k^*$. ϵ_{it} are the error vectors.

The vector of both domestic and foreign variables of a country's local model is denoted $\mathbf{z}_{it} = (x_{it}^{'}, x_{it}^{*'})^{'}$. We can then through these $\mathbf{z}_{it}$ vectors express (2) as

$$\mathbf{A}_i 0 \mathbf{z}_{it} = \sum_{\ell=1}^{p} \mathbf{A}_{i\ell} \mathbf{z}_{it-\ell} + eps_{it} \quad (3)$$

In the equation above, $\mathbf{A}_{i0} = (\mathbf{I}_{k_i}, -\Lambda_{i0})$ and $\mathbf{A}_{i\ell} = (\Phi_{il}, \Lambda_{il}$ for $\ell = 1, 2, ..., p$. Furthermore, $p = max_i(p_i, q_i)$, $\Phi_{i\ell}$ for $\ell > p_i$ and $\Lambda_{i\ell} = 0$ for $\ell > q_i$. Equation (3) rewritten in the error-correction form containing the first differences then gets us (4):

$$\Delta x_{it} = \Lambda_{i0} \Delta x_{it}^{*} - \Pi_i z_{i,t-1} + \sum_{\ell=1}^{p} \mathbf{H}_{i\ell} \Delta \mathbf{z}_{i,t-1} + \epsilon_{it} \quad (4)$$

In the last equation, $\Pi_i = \mathbf{A}_{i0} - \sum_{\ell=1}^{p} \mathbf{A}_{i\ell}$ and $\mathbf{H}_{i\ell} = -(\mathbf{A}_{i,\ell+1} + ... + \mathbf{A}_{i,\ell+p})$. Furthermore, the rank of Π_i gives the total count of the cointegrating relationship between variables within z_{it}. Importantly, cointegration in the model is possible between different domestic variables but also between a domestic variable and a country-specific foreign variable. After estimating local submodels, the GVAR procedure builds from them a single global model. For this, the so-called "link" matrices based on the weight matrices are used. Link matrices are $\mathbf{W}_i = (\mathbf{E}_i^{'}, \tilde{\mathbf{W}}_i^{'})$ where $\mathbf{E}_i$ is a selection matrix of size $k \times k_i$ selecting $\mathbf{x}_{it}$ such that $\mathbf{x}_{it} = \mathbf{E}_i^{'} x_t$. Using these matrices, we can rewrite $\mathbf{z}_{it}$ as

$$\mathbf{z}_{it} = (\mathbf{x}_{it}^{'}, \mathbf{x}_{it}^{*})^{'} = \mathbf{W}_i \mathbf{x}_t \quad (5)$$

Substituting in (3) we can get

$$\mathbf{A}_{i0}\mathbf{W}_i x_t = \sum_{\ell=1}^{p} \mathbf{A}_{i\ell}\mathbf{W}_i x_{t-\ell} + \epsilon_{it}$$

The GVAR model stacks all these local models, i.e. stacks for all i. Thus, we get

$$\mathbf{G}_0\mathbf{x}_t = \sum_{\ell=1}^{p} \mathbf{G}_\ell \mathbf{x}_{t-\ell} + \epsilon_t \tag{6}$$

Error terms can be in this case described as $\epsilon_t = (\epsilon_{1t}^{'}, ..., \epsilon_{2t}^{'})^{'}$ and the matrix G_ℓ is

$$\mathbf{G}_\ell = \begin{pmatrix} \mathbf{A}_{1,\ell}\mathbf{W}_1 \\ . \\ . \\ . \\ \mathbf{A}_{N,\ell}\mathbf{W}_N \end{pmatrix}$$

Provided that it is possible to invert $\mathbf{G}_0$, the solution of the whole model can be finally derived by multiplying equation (6) by the inverted matrix $\mathbf{G}_0^{-1}$. The solution that gives us the vector of all variables can be then expressed as seen below.

$$\mathbf{x}_t = \sum_{\ell=1}^{p} \mathbf{F}_\ell \mathbf{x}_{t-\ell} + \mathbf{G}_0^{-1}\epsilon_t \tag{7}$$

The matrix $\mathbf{F}_\ell$ is $\mathbf{F}_\ell = \mathbf{G}_0^{-1}\mathbf{G}_\ell$.

The model has to be in our case further extended because of the inclusion of common global variables - the three financial stress indexes. Common variables ω_t change the individual countries' models in the following way:

$$\mathbf{x}_{it} = \sum_{\ell=1}^{p_i} \Phi_{i\ell}\mathbf{x}_{i,t-\ell} + \Lambda_{i0}\mathbf{x}^*_{it} + \sum_{\ell=1}^{q_i} \Lambda_{i\ell} x^*_{i,t-\ell} + D_{i0}\omega_t + \sum_{\ell=1}^{s_i} D_{i\ell}\omega_{t-\ell} + \epsilon_{it} \quad (8)$$

Common variables can enter the model also through the dominant variables approach introduced by Chudik and Pesaran (2013), where a dominant unit model is created for the global variables. This is also the default setting of the GVAR Toolbox by Smith and Galesi (2014). However, we exclude from our model the default common variables of the Toolbox (oil prices, metal prices, and prices of raw materials) and use only the three FSIs as common variables. These can be incorporated in the model in a simple way without using the dominant unit model. Our three global variables hence act as some common factors for all the models. In the local models they directly relate to, i.e. either for the euro area, the US, or the UK, they are treated as endogenous variables.

For the purposes of the thesis, we are interested mainly in the impulse response analysis that can be done by the model. Just as for any other type of VAR modeling, we can try to stimulate a shock to a particular variable and observe the predicted responses of other variables. In our case, the variables that should cause the shock are the FSIs - even though they are global variables, they are set as endogenous in the economies whose financial markets they proxy, and the shock hence originates in those particular countries' submodels. The impulse response analysis then allows us to construct the impulse response function, which captures the forecasted values of all the variables following the shock.

Again following Chudik and Pesaran (2016), we can illustrate how the IRFs are calculated by the model building on the simpler equation giving the model solution, that is on the equation (7). Presuming there are k distinct structural shocks, their identification process can be described by the equation $\mathbf{v}_t = \mathbf{P}^{-1}\epsilon_t$, where $\mathbf{P}$ is the $k \times k$ matrix of contemporaneous dependence (and ϵ_t refers to the already-defined vector of country-specific errors). $\mathbf{P}$ has to be set such that $\sum = E(\epsilon_t \epsilon_t^{'})$=$\mathbf{PP'}$. This leads us to the following expression for the $k \times vector$ of structural impulse response functions for $j = 1, ..., k$:

$$\mathbf{g}_{vj}(h) = E(\mathbf{x}_{t+h}|v_{jt} = 1, \mathcal{I}_{t-1}) - E(\mathbf{x}_{t+h}|\mathcal{I}_{t-1}) = \frac{\mathbf{R}_h \mathbf{G}_0^{-1} \mathbf{P} \mathbf{e}_j}{\sqrt{\mathbf{e}_j^{'} \sum \mathbf{e}_j}} \tag{9}$$

$\mathcal{I}_t = \{x_t, x_{t-1}, ...\}$ from the equation (8) is the information set containing all the available information at time t and $\mathbf{e}_j$ refers to a $k \times 1$ selection vector for j. The matrices $\mathbf{R}_h$ of size $k \times k$ are recursively calculated as $R_h = \sum_{\ell=1}^{p}$ with $R_0 = I_k$ and $R_\ell = 0$ for $\ell < 0$.

The shock identification process raises technical issues that can be resolved through various methodological approaches. A common method used in the VAR modeling in general is for instance the sign restrictions approach, under which expected signs/directions of changes in certain variables are a priori set based on theoretical expectations about these variables. One of the steps in preparing a VAR model for an impulse response analysis is typically also ordering of the variables - this revolves around building the matrixes of variables so that the variable theoretically assumed to influence all the other variables being placed at the top with the variable assumed to be influenced by all the others placed at the bottom. It is, however, much more difficult to use the ordering of variables or other more conventional methods for impulse response analysis when it comes to the GVAR model. Although it is not impossible, given the overall high number of all the country-specific variables, it would be challenging to impose a priori restrictions on the model. For the GVAR modeling, another approach has been found suitable - the generalised impulse response function (GIRF) method. This approach has been used in the foundational works on GVAR by Pesaran et al. (2004) and Dees, di Mauro, Pesaran, and Smith (2007) and it can also be deployed when using the standard GVAR toolbox by Smith and Galesi (2014). Originally, this method was developed by Pesaran and Shin (1998), building on the earlier work by Koop et al. (1996). The GIRF method presents in a sense a less restrictive alternative to conventional IRF methods that have been longer in use. Crucially, as has already been said, it is not necessary to order variables under this approach and so the variables enter the model in the thesis unordered.

The $k \times 1$ vector of GIRFs, building still upon the simpler version of the model given by the equation (7), with $j = 1, ..., k$ and $h = 0, 1, ...$, can be in the end expressed in the following way:

$$\mathbf{g}_{\epsilon j}(h) = E(\mathbf{x}_{t+h}|\epsilon_{jt} = \sqrt{\sigma_{jt}, \mathcal{I}_{t-1}}) - E(\mathbf{x}_{t+h}|\mathcal{I}_{t-1}) = \frac{\mathbf{R}_h \mathbf{G}_0^{-1} \sum e_j}{\sqrt{e_j^{'} \sum e_j}} \tag{10}$$

Importantly, the size of the shock $\sqrt{\sigma_{jt}} = \sqrt{E(\epsilon_{jt}^2)}$ is equal to one standart deviation of ϵ_{jt}.

3.2 Variable Selection

The model is built upon the default GVAR settings and data provided by the GVAR toolbox 2.0 by Smith (2014) and the recently updated version of the GVAR dataset by Mohaddes and Raissi (2024) with the data sample ending in the third quarter of 2023. The baseline model's setup includes as local variables used in each country's model all the usual suspects, that is GDP, inflation, interest rates /both short term and long term), exchange rates as well as equity prices. The model then includes also three global variables – oil prices, raw metal prices, and metal prices, which enter it through a dominant unit model. The key modifications done in the thesis are the inclusion of the CISS financial stress indexes (which also serve as the source of the shocks studied) and the so-called shadow rates (when applicable) instead of the default short-term values for the euro area, the US, and the UK.

All three default global variables are omitted since they are of no particular interest in our case and their inclusion, requiring the use of a dominant united model, could be an unnecessary overcomplication of our model (which already has three global variables regarding finance). Long-term interest rates are also omitted, as shadow rates are used for the three countries for some quarters instead of the original short-term rate. With this modification, also including the original data on long-term rates may appear problematic. It could perhaps be argued, that equity prices could also be left out in order to simplify the model, as they are typically used as proxies for financial sector and we already include the financial indexes with this aim. Equity prices can, however, still be important for us as they can of course serve as proxies for the financial sectors of all the countries for which the CISS index is not available. Furthermore, an attempt to also exclude equity prices would leave the model with only four domestic variables in individual local models and make the model unstable. Hence, equity prices shall clearly remain in our model.

A detailed commentary on incorporating financial stress indexes (FSIs) and shadow rates into the model is provided in the next two subsections.

3.3 Financial Stress Index

As has already been discussed, one of the key attributes of the model in the thesis is the use of the financial stress index, specifically the ECB's composite indicator of systemic stress in the financial system (CISS) created by Holló, Kremer, and Lo Duca (2012). Just as the proxies for financial shock, which ordinarily appear in the research literature, this indicator is also based on certain key variables that may be conventionally used to illustrate the situation in the financial markets.

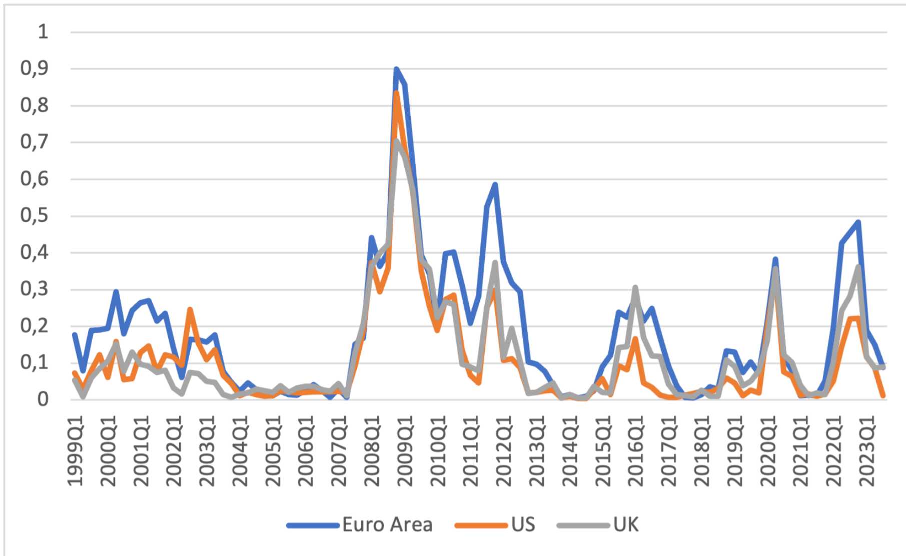

Figure 1: CISS values included in the model

However, using CISS may seem in some regards superior to other options – while simpler proxy variables conventionally used in similar research are typically based around essentially just one or very few main variables concerning the financial markets (most conventionally perhaps only the equity markets) CISS is constructed in a complex way by using the inputs from a wide variety of data series.

The index is namely built upon the data capturing the bond, equity, money, and forex markets as well as financial intermediaries. For each of these segments, three variables are used, many of them already being derived as transformations or aggregations of other more specific variables. All these components of the index are in the end aggregated together so that one final value expressing the stress level of the financial system is created. Such an elaborate way of constructing the financial stress variable naturally appears well out of the scope of any research merely using the variable for modeling and not dedicated solely to capturing financial stress. Hence, the availability of the official "high-quality" pre-calculated index such as CISS seems to be a source of much ease and precision for the modeling in the thesis.

Observing the CISS index values for the euro area, we may see that it would not climb above 0,4 until the outbreak of the 2007 crisis. We could then essentially identify two main spikes in the financial stress levels. Firstly, it would be just after the start of the global crisis (that is after the financial crisis from the US transmitted globally) – in 2009, approximately when the European sovereign debt crisis was starting, this spike got much greater in magnitude and the index for the only time grew even above 0,8 (we could see this perhaps as some kind of a "sub-spike" capturing the "sub-crisis" of the Global financial crisis). After rather quickly falling to more conventional levels, the indicator again rapidly rose to what we could deem as extremely high values and returned back to some kind of normalcy later in 2012. These developments may of course be seen as somewhat coinciding with the execution of the unconventional monetary policies by the ECB and with the extraordinary behavior of the shadow interest rates.

While a notable growth of the index can be seen also during the outbreak of the COVID pandemic, it does not reach values comparably high to those of the post-financial crisis times. This is perhaps not as surprising given the non-financial character of the COVID crisis and the extremely loose monetary policies at the time. It is actually only as the pandemic started to fade out and inflation embarked on the path of rapid growth that the CISS returned to the territory of extremely high financial stress. Particularly huge increases in the values can be observed in the days just after the start of the Russian invasion of Ukraine. Although this second very recent large spike in financial stress seems to be getting over now, it may surely be a very interesting feature of the data sample used that it still includes it.

A further advantage of the ECB's CISS index is the availability of the indexes calculated with the same methodology also for certain important non-euro area countries, most importantly the United States. For the US economy, another highly credible source of data on financial stress levels exists, namely the St. Louis Fed financial stress index. Even though this measure may perhaps seem like the best index to be used for the US simply because it is calculated by the Fed rather than by the ECB, the CISS can still be deemed much preferable for the data of the thesis due to the consistency in the methodology, and it is still this measure that is opted for in the thesis. An interesting observation, which unfortunately does not seem to add to the appeal of the indicators as error-proof measures of financial stress, is that there is a clearly visible difference between what the two measures might tell us about the levels of stress in the US financial system at certain times. Although the values of the indexes are not comparable, we may compare the differences between the magnitudes of spikes. The most notable specific feature of the CISS data is the large increase in 2022 – the index reached almost similar values as in 2008. Looking at the measure by the Fed, on the other hand, the increase in 2022 does not seem extraordinary at all and is surely not by any means comparable to the GFC spike that stands out much more extremely in the Fed index. An interesting feature of the US CISS data when compared with the euro area is the much greater relative importance of the increase in financial stress during the pandemic – this is documented by the Fed index as well, where the 2020 Covid spike is the only truly notable one after 2008/2009.

Although the indexes of the euro area and the US are the two crucial ones for our model, the CISS index for the UK is included as well simply since in this case it is also available throughout the whole sample. The other two indexes could be expected to be much dependent on the US one too and so in general it could be argued that only the index for the US financial sector as by far the largest in the world should be included. The indexes enter the model as global variables, meaning that they affect our whole system of countries' models. As is typically done for global variables in the GVAR modeling, they are set as weakly exogenous for all the individual local models except for the economies they are directly related to – the euro area FSI is set as an endogenous variable in the model for the euro area and conversely for the US case. Due to the potentially large impact of the financial stress levels in the US on other economies (on the euro area perhaps in particular) or even for example the potentially large effect of the euro-wide index on neighboring countries, it may seem that the two indexes could each be set as endogenous perhaps even for other economies. However, we cannot explore such options, as the GVAR model does not allow for a global variable to be endogenous in more than one local model. All in all, the option with the two indexes being global variables weakly exogenous for other countries and endogenous in the concerned economy (euro area, US, or UK) appears as a reasonable and suitable setting for the model in our case.

3.4 Shadow Rates

Although the concept of shadow interest rates was known even well ahead of the Global financial crisis, it naturally gained much attention in the post-crisis environment of deflation fears and extremely low interest rates, when many economies, including the US, were approaching zero lower bound. Wu and Xia (2016) create a feasible way of calculating the shadow rates and importantly also show their importance for the macroeconomic developments after 2009. Unlike the conventionally used interest rates – in the US these would be the effective federal funds rates (EFFR) – shadow rates may go below zero and are hence able to reflect the unconventional monetary policies that central banks resorted

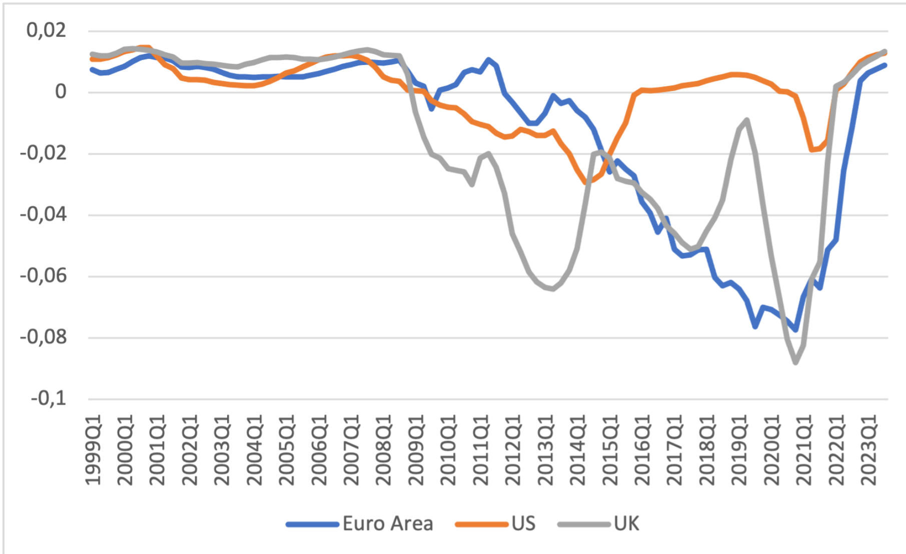

Figure 2: Short-term rates values with the shadow rates included

to in an effort to stimulate the economies hit by the crisis.

Looking at the data on shadow rates, we may get an image of how important an aspect unconventional monetary policies have been in the post-crisis financial world. Wu and Xia (2016) proposed originally the way of calculating the shadow interest rates for the US economy – their US data now also cover the pandemic period. While in the "normal" times the shadow rates closely follow the EFFR, having the same or almost the same value, the situation changes dramatically in 2009. Following a sharp decrease, the Fed funds rates remain at (or very close to) zero till late 2015. Throughout this whole period, shadow rates achieve negative numbers, reaching almost -3% during 2014. As rare as this episode of monetary policy may have appeared, it actually occurred once more just a few years later during the COVID pandemic, although this time for a much shorter time.

While these two periods of negative rates may already make the inclusion of shadow rates seem relevant, the development in the US can be still deemed rather tame compared to the euro area. Wu and Xia (2017, 2020) bring modifications to the original method, which are used for the computation of the euro area shadow rates. Although the shadow rates did cross into the negative territory at approximately the same time as those in the US, they were somewhat oscillating around zero for a couple of years, which we may view as reflecting the initial hesitancy of the ECB towards unconventional monetary policies. From 2014, the behavior of shadow rates changed markedly – their values started decreasing much below zero in a constant and relatively sharp way. This dive into the negative territory was much deeper than in the US – for several years the rates were well below -2%. Crucially, the rates were still negative as the global pandemic started in 2019, and in response it, dropped even further, reaching as low as -7%. Wu and Xia end their euro area dataset in 2022, as they deem shadow rates to have been since identical with the official ECB rates – it is only at this very recent point of time when they can the rates can be seen as finally reaching positive numbers again. It is thus no exaggeration to speak of an entire decade of negative interest rates in the case of the ECB. Since the thesis is focused on the euro area, the inclusion of shadow rates appears essential and potentially consequential for the model. Hence, the shadow rates as given by the datasets of Wu and Xia are used in the model instead of the official rates. This is done of course most importantly for the euro area itself, but also for the US and for the United Kingdom – another crucial non-euro country, where the shadow rates as calculated by Wu and Xia remained negative for even more quarters than in the EU.

In the dataset by Mohaddes and Raissi (2024), some of the values in the default are actually below zero as well but this is so only for a much shorter period of time and the values are crucially still very close to zero as opposed to the Wu and Xia rates. For the period between the first and the last quarter when the shadow rates attain negative values, they are inserted instead of the original data. Since the default values just before and after the periods when shadow rates are used are very close to zero, the transition between the original values and the ones they are replaced with is quite smooth and should hence hopefully not distort the interest rate data, although it may still not be as "perfect" as when only the one metric from one source is used throughout the whole sample. For the euro area, the concerned period is 2009Q3-2022Q4, for the US and for the UK it is 2009Q3-2021Q4.

3.5 Sample

A major disadvantage of the focus on the euro area may appear to be the fact that it essentially shortens the sample that can be used for the research. For example the data on the GDP of the euro area can be easily calculated even for the years before the actual creation of the monetary union, incorporating variables capturing the financial stress or monetary policy in line with the methodological intentions of the thesis' model seems to be truly meaningful only for the time period since the creation of the euro area, that is since 1999. Certain data for the euro area, crucially namely the CISS index, are available only for this period. The 1999-2023 sample could appear rather short compared to the time period of the GVAR dataset, which begins already in 1979. However, focusing only on the years 1999-2023 may in the end not be as much of a disadvantage. Earlier works using the GVAR model used data from similarly long or even shorter periods. Furthermore, much of the older research mentioned in the literature review uses in fact the data ending approximately around the time when the common currency area was born, i.e., around the break of the millennium. Even the older works more focused on the euro area include in the studied samples often only a few years during which the euro area already existed. Hence, the use of the data starting only in 1999 may perhaps make the expected increased validity of the model stemming from the inclusion of the most recent years seem even more profound.

Euro area is included in the model following the default setting of the toolbox and database, which includes actually only 7 of the original members – Austria, Belgium, Finland, France, Germany, Italy, the Netherlands, and Spain. This might naturally seem like a too narrow definition, especially for a thesis focused particularly on the euro area. These omissions can, however, seem justifiable and reasonable.

Luxembourg and Ireland, although original members, are very specific cases, since they are very small but at the same time have traditionally an important role in global finance and commerce. They could hence potentially make some distortions in the data and in the model if included. Countries that have entered the euro area later are problematic already due to simply not being part of the monetary union throughout the whole sample. They would also not be expected to bring much important information to the model as they are quite small economies, maybe with the exception of Greece, which is nevertheless still much smaller than the key EU economies. Portugal is the only country that seems to be includable without any issues, as it is one of the founders of the euro area and at first sight appears as a "conventional" country from the economic/financial viewpoint. I have still decided to simply follow the original settings of the toolbox and the dataset and hence not add it, as adding the data manually to the preprepared ones could be somewhat problematic and Portugal does not appear to be as important for the euro area as to be worth the potential difficulties. It is important to note that there has long been a debate about there being a core and a periphery in the euro area - besides the members that have joined later, several original members are typically considered to be a part of the periphery - namely Portugal, Ireland, and Greece (De Grauwe and Ji, 2018; Wortmann and Stahl, 2016). The Economists' Voice, 15(1), 20180027.. This may further justify their omittance, as to capture the euro area, we mainly need the core economies that would be naturally expected to be the principal drivers of developments in the currency union (in normal times at least). As part of the southern periphery, we could in fact consider even Italy or Spain, however, these seem to be relatively too large to be left out.

The definition with the 7 countries listed above importantly includes all the four major euro area economies – Germany, France, Italy, and Spain, the most important being the inclusion of both France and Germany at the same time. The model allows us to study them as a single economy, with the individual countries' data being averaged to create a single local model for the euro area. The variables expressing short-term interest rates and financial stress already have the same values across all these 7 countries before the computation of the model starts.

I have also opted for the simplest option of following the original settings for the selection of other countries. Hence, the model sample contains the following 25 countries outside of the euro area: Argentina, Australia, Brazil, Canada, Chile, China, Finland, France, Germany, India, Indonesia, Japan, Malaysia, Mexico, Norway, New Zealand, Peru, Philippines, Saudi Arabia, Singapore, South Africa, South Korea, Sweden, Switzerland, Thailand, and Turkey. It appears to me that the most interesting other countries, besides of course the US and the UK, could in our case perhaps be China, Japan, South Korea, Canada, and other notable economies of western or northern Europe that do not use the euro – Norway, Sweden, and Switzerland.

3.6 Model Specification

The model is run using the GVAR toolbox 2.0 for Matlab by Smith and Galesi (2014). Following the theoretical foundations, domestic variables are generally set as endogenous for the local models of their respective countries while foreign variables are set to enter the local submodels as weakly exogenous.

If we follow the standard example of Dees, di Mauro, Pesaran, and Smith (2007), however, certain modifications should be made. In accordance with this work, and with the default settings of the Toolbox, we set in our local model for the US foreign equity prices and short-term interest rates as exogenous. This should somehow incorporate into the model the specificity of the US economy stemming from its size and global influence. Nonetheless, as has already been mentioned during the discussion of the FSIs, the two other FSIs are still set as weakly exogenous in the US model. Since they are more direct indicators of the state of the markets than equity prices, this difference between how these variables enter the US model may hopefully not be deemed problematic.

A more problematic case might, however, be the settings regarding the exchange rates. Following again Dees, di Mauro, Pesaran, and Smith (2007), the domestic US exchange rate is, as the only domestic variable in the whole model, not set as endogenous but as weakly exogenous, while foreign exchange rates enter the US model as weakly exogenous as well. This could somehow account for the specific role of the US dollar. Dees, di Mauro, Pesaran, and Smith (2007) and consequentially also the default version of the Toolbox also make another modification that so to speak mirrors the one for the US exchange rate - while exchange rates for all the other countries enter domestic models as endogenous, foreign exchange rates are set as (strongly) exogenous. Due to our focus on the euro economy, I have, however, been somewhat afraid of this modification that could change the response to changes in the euro exchange rate, and have hence not made this modification. This means that for countries besides the US, domestic exchange rates are endogenous, and foreign exchange rates are weakly exogenous. These details of the specification might be deemed contentious and a different setting could surely be considered. Nonetheless, I hope that this details should not be much important in our case, as in our shock scenarios, the effect on the exchange rates is not a crucial part of the results - we are much more focused on the consequences of the shock on other two FSIs, and both domestic and foreign equity prices and real GDPs.

As has already been said, the three FSIs enter the model as global variables. They are included in perhaps the most straightforward way so that they are endogenous in the model of the country whose financial sector they represent and weakly exogenous in all the others. We could be thinking of adding the US FSI as endogenous also for the euro area or the UK if we presume the influence of the US financial markets on the economy that interests us the most would be so large as to make its FSI essentially wholly dependent on the US one. This is though not possible in the GVAR model - global variables can be added to the model as endogenous for at most in one country. Hence we do not have to think of any other options than setting the FSI endogenous in the countries they directly relate to. It may nevertheless still seem viable to set the FSIs for the euro area and the UK as exogenous in the US, following the example for the foreign equity prices in the US submodel. I have decided to not do so and just follow the simple option of setting them as weakly exogenous for all foreign countries including the US. Unlike in the default setting with oil and material prices as global variables, no dominant unit model is utilized to include our global variables - variables such as oil and material prices require the use of the dominant unit model as it would not make sense to include them as endogenous in any specific country, being in this sense truly "global". Using only FSIs as global variables hence makes the incorporation of global variables into the model easier.

The most important tools of our analysis are the global impulse response functions (GIRFs or just IRFs) derived from a shock simulation. They show us the projected behavior of variables in response to a shock to a certain variable. We are interested in studying shocks to the FSIs, most importantly to the one for the euro area and crucially also for the US. Although the case of the UK is not as interesting for us, simulation of the shock to the UK FSI is also performed. A shock to the FSI means a sudden increase in it. We are hence simulating how variables in the economies around the globe would respond to a shock increase of financial stress in the euro area, the US, or the UK.

The forecasts are made for 40 periods ahead, so for 10 years. Besides the main median estimate, we also need to get upper and lower to confidence bands to get a whole confidence interval for our forecasts giving us a great option to see essentially how certain the model is with its own forecasting for each variable. In the GVAR, this is done through bootstrapping. Specifically, 1000 bootstraps and shuffle method are selected in our model. It also shall be noted that a block diagonal covariance matrix is selected to be used for the forecasting in the model. It is due to this method potentially being able to account for the fact that numerous economies in our sample are relatively smaller and less influential and should hence not have much impact on the larger ones in the model. Any remaining settings of the model were left as they are by default.

As has already been said in the section on the GVAR theory, trade flows data from the GVAR dataset by Mohaddes and Raissi (2024) are used for the weight matrix. More specifically, the program of the GVAR toolbox by Smith and Galesi (2014) uses trade flows data from the 1980-2016 period to create a matrix of fixed weights, which is then used as the weight matrix of our GVAR model. Any remaining settings of the model were left as they are set by default in the GVAR toolbox by Smith and Galesi (2014).

4 Results

The crucial part of the output of the model for us are the impulse response functions (IRFs), which show us the projected responses of the variables to a shock increase in the given FSI. Nonetheless, the model provides a lot of other outputs that provide much information on the characteristics and estimated relations of the model. During IRF analyses, results of Forecast Error Variance Decomposition (FEVD) are often discussed. This is essentially a complement to the IRFs providing further insight into how variables affect and explain each other. While the GVAR model procedure generates also Generalized FEVDs (GFEVDs), we may skip discussing these results for brevity, as the IRFs are simply the crucial part of the output in our case. The results below include the graphs of the IRFs, however, not all of them, as this could take too much space. All the graphs for the euro area shock are presented but in some cases the graphs for the US shock, and in particular for the UK shock, are omitted. Nonetheless, all these graphs can be found in the appendix. I may note here I have decided not to include in the appendix any other parts of the output, for example the tables with the details of subomdels of individual countries, as the remainder of output is large and would require a lot of space to be presented, and at the same time it may not be deemed as important given our rather narrow focus.

While it is generally not necessary given our aims to discuss the whole output in more detail, we shall still start this by summarizing the results of the tests for weak exogeneity since they are important for assessing the validity of our model specification. We can then move to the summary of the results that can be drawn from the IRFs. First, the impact of the simulated shocks to the remaining two FSIs is discussed followed by the assessment of the projected impacts on the equity prices. These two subsections hence provide the overview of how the model would predict the shocks to affect financial markets in other economies. The results for real GDP (and hence the possibility of the shock affecting the whole economy) are described next. The discussion of the results for the remaining variables is then also presented. We continue with the discussion of how the inclusion of shadow rates appears to affect the model. Finally, a summarizing commentary of the results trying to compare them with those in previous research is provided.

4.1 Weak Exogeneity Tests

Country	F test	Fcrit_0.05	ys	Dps	rs	eqs	eps	fsiu	fsieu	fsiuk
ARGENTINA	F(1,82)	3,95738832	0,18811216	0,09764115	1,14898031	0,1417017	0,96059003	0,12461013	1,18338276	0,29925194
AUSTRALIA	F(2,81)	3,10931055	1,66960433	0,57594283	1,28194452	0,83992465	0,62513231	0,12728884	0,11071703	0,28112721
BRAZIL	F(2,82)	3,1078913	0,09913176	1,22519016	0,05041177	0,76693672	0,2322714	2,21272247	3,12028864	2,64733028
CANADA	F(3,80)	2,71878498	1,50982865	0,69847311	1,36949236	3,49929753	1,2253646	2,79797834	3,09015608	2,54954418
CHINA	F(1,83)	3,95596101	12,3644819	2,36358059	0,32810841	0,00762406	0,64338474	0,96248375	3,94827672	4,09535531
CHILE	F(3,80)	2,71878498	1,59854876	0,27169274	1,01375997	2,18523601	1,853149	0,16294503	0,18720019	0,27258679
EURO	F(2,81)	3,10931055	2,70270027	0,59269996	2,33405359	0,34218236	0,69336585	2,05790375		1,73378264
INDIA	F(3,80)	2,71878498	2,41324006	2,61850045	2,23176811	0,6286061	0,61794556	2,56912258	4,35736969	2,34180349
INDONESIA	F(2,82)	3,1078913	0,98353671	0,40943925	0,24289287	0,86810216	1,99641675	0,21097119	0,66947755	0,66233049
JAPAN	F(2,81)	3,10931055	0,02971225	0,60686884	0,34820346	0,17713047	2,86976008	0,07311365	0,25999959	0,06328784
KOREA	F(3,80)	2,71878498	0,53541494	0,24797233	2,38316106	1,68849366	0,5928913	1,76237902	1,70689631	1,27281098
MALAYSIA	F(1,82)	3,95738832	6,15979517	5,02826997	0,00581269	4,94519806	0,03319725	6,48997171	3,71138838	5,32567194
MEXICO	F(1,83)	3,95596101	0,30392692	0,00319508	0,01933871	0,32586441	3,81208917	0,12956912	0,32186924	0,31859468
NORWAY	F(2,81)	3,10931055	1,00992895	2,08286468	0,99999337	0,43598205	0,6107424	5,82114114	9,59713902	3,20941407
NEW ZEALAND	F(1,82)	3,95738832	0,08225578	0,25859796	1,0753062	0,03116313	3,22221117	1,03879432	1,56818034	2,5389061
PERU	F(3,81)	2,71734273	0,86615149	0,46600679	0,09226065	0,16700876	0,84225713	0,41503122	0,56341804	0,23206227
PHILIPPINES	F(1,82)	3,95738832	0,00987312	0,82184182	1,60238965	0,06191179	1,18055502	0,45533982	0,00407705	0,15540963
SOUTH AFRICA	F(3,80)	2,71878498	0,5993677	0,49085673	0,92683616	0,91930773	0,66502207	0,40238155	0,07300936	0,39354211
SAUDI ARABIA	F(1,84)	3,95456841	0,02810319	0,04615223	1,86621179	1,16389627	0,07478976	1,34211822	0,89669448	0,292549
SINGAPORE	F(1,82)	3,95738832	0,03228611	0,63142911	0,00556595	1,56175407	0,61269621	2,42437084	2,81599446	3,98445294
SWEDEN	F(4,79)	2,48736595	1,28609102	1,02179447	3,21876678	0,56623602	0,99455448	1,87532016	2,1025491	1,17732607
SWITZERLAND	F(2,81)	3,10931055	0,46565076	1,77927286	1,82919419	2,54296703	1,28669974	0,69771947	1,17993887	0,30795224
THAILAND	F(2,81)	3,10931055	0,36806807	2,10072046	2,5151259	0,13544308	2,34540777	0,16830847	0,01263648	0,1051778
TURKEY	F(1,83)	3,95596101	0,21163742	0,03360669	1,2758596	0,30470026	0,26824702	0,06300417	0,20131666	0,08914145
USA	F(1,84)	3,95456841	0,31947339	0,10489721			2,32794776		0,00055334	0,54714031
UNITED KINGDOM	F(4,79)	2,48736595	2,57178074	0,97835556	0,17485705	1,58990357	0,32149352	0,94944395	1,15746578	

Figure 3: Weak exogeneity test results

As has been mentioned earlier, weak exogeneity is an important assumption in the model. The GVAR toolbox by Smith and Galesi (2014) performs during the modeling F-tests of weak exogeneity everywhere where it is specified. In our model specification, that is the case of all foreign variables for each individual country except foreign rates and equity prices in the US model and also for all our three global variables (the FSIs).

We may first look at the FSIs, since they are an addition to the standardly used variables and a failure to meet the weak exogeneity assumption would make them seem improper for the model. Fortunately, the tests generally allow us to presume weak exogeneity at the 5% significance level. There only a few cases where the condition to pass the test at the 5% level is not met. Notably and perhaps somewhat confusingly, the assumption is shown as potentially rejectable for all the free indices in the local submodel of Norway – while the FSI of the UK is still quite close to the 5% criterion value, those of the US and the EU are relatively clearly further away from it. The FSI of the EU also misses the 5% threshold value by not as large margins for Brazil and Canada and by a larger margin for India. The FSI for the US misses the criterion narrowly in Canada's model and more clearly in Malaysia's. Finally, the index for the UK also fails to meet the condition rather narrowly for China and Singapore and by a relatively large margin for Malaysia.

Despite all these cases, I think we could overall deem the inclusion of the FSIs from the weak exogeneity viewpoint quite successful. For all the remaining 64 possible combinations the indices of financial stress appear to meet the weak exogeneity assumption. It would naturally be preferred if there were no cases where the condition could be deemed problematic, but the relatively low number of these instances still allows us to see our model as viable. Since weak exogeneity is essentially just a less restrictive case of strong exogeneity, if we decide to strictly follow the results in those cases where weak exogeneity seems not to be supported, we would be inclined to turn towards endogeneity. Still, the FSIs are from a non-econometric viewpoint perfectly internal parts of the models by definition only in those economies whose financial stress levels they are expressing, so we may simply stick with our baseline specification.

If we look beyond the global variables, the assumption again appears to be broadly met, with even fewer problematic cases. The most problematic appears to be Malaysia, where foreign GDPs, inflation rates, and equity prices all fall behind the 5% threshold. Other cases where there seems to be a problem with the weak exogeneity assumption are foreign GDPs for China and the UK, foreign short-term rates for Sweden, and foreign equity prices for Canada. Again, if we strictly followed the results, we could change the specification to endogeneity in these cases, or in the case of Malaysia, we could consider dropping the country altogether as it is not particularly important for the aims of the thesis. Again, we may still just follow the original specification, as there are only very few problematic cases and it does not (hopefully) seem that these particular cases would cause a major issue for the shock simulations we are interested in. Overall, the weak exogeneity condition appears broadly satisfied, crucially with seemingly no problems in this regard in the case of the euro area (neither in the case of the US). Nevertheless, we should keep in mind that our specification simply might not be perfect and some alterations to it would be possible.

4.2 FSIs

Looking at the predicted reactions of the FSIs in the US and the euro area to the US shock, we may clearly see a great degree of similitude. This is so not only for the patterns but also for the magnitudes – the median estimates are in both cases

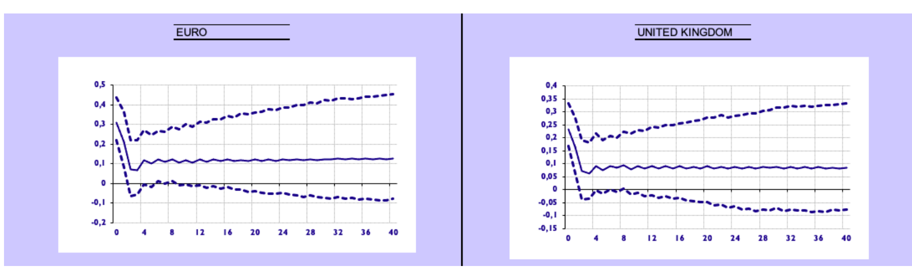

Figure 4: Response of financial stress levels to the euro area shock

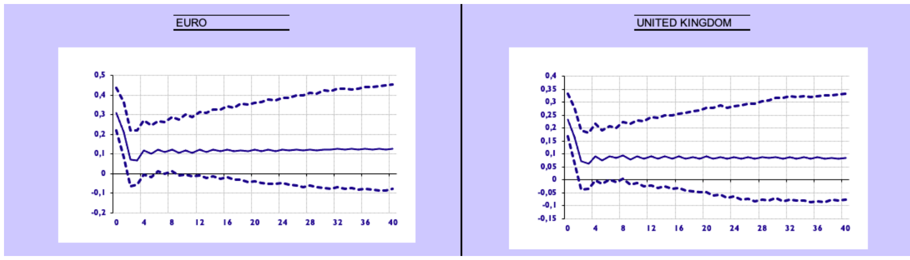

Figure 5: Response of financial stress levels to the US shock

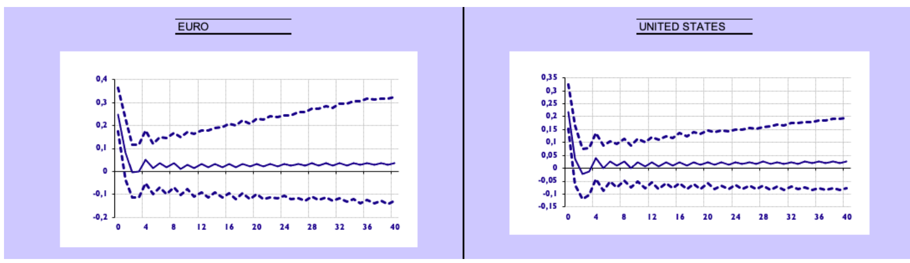

Figure 6: Response of financial stress levels to the UK shock

very close to each other. Although the lower bounds of the confidence interval allow for a possibility that the shock increase in financial stress levels wears off relatively quickly and there is then a decrease in the FSI, the IRFs overall seem to suggest that it is very likely the increase in financial stress continues at some smaller rate even long after the shock. Median estimates suggest that the growth of the FSI should stabilize at approximately 0,1 in both economies and it is shown to persist even 40 periods ahead, that is even after 10 years. We could ascribe this to the heavy influence of the once-in-a-lifetime financial crisis in our sample that may be naturally presumed but it may still seem perhaps somewhat surprising that the forecasts do not suggest overall a decreasing trend towards the end of the forecasted period. What is perhaps also interesting is that the upper bounds and median estimates for the euro area are even slightly above those for the US, the actual originator of the shock in this scenario. On the other hand, the lower bound moves noticeably further away from the 0 axis with time, suggesting that the eventual start of a decrease in financial stress is somewhat more likely. All in all, looking just at these IRFs, it appears that the model suggests an extremely strong shock transmission channel between the US and the euro area. In a simplified way we could say that a financial shock in the US might be expected based on the predictions to produce an immediate reaction of more or less the same magnitude in the euro area.

The projections for the effect of the shock originating in the euro area on the domestic FSI are considerably grimmer than in the US case. Even the lower bound remains throughout the whole forecast period at or above 0. Based on these IRFs we could hence practically with certainty expect that financial stress levels in the euro area would after a shock increase remain increased for a long time. In fact, it seems very probable that the shock would cause the euro-wise financial stress level to remain getting worse for a long time. Unlike in the US case, there is a clear increase in the median estimate after the initial drop. Median values stabilize somewhere below 0,3 – significantly above the US case where it is around 0,1. Furthermore, the upper bound suggests in this case that there is in worst cases room for the FSI's growth to get a very fast pace.

While the effect of a shock to the European FSI clearly seems to have a much larger effect on the variable itself compared to the US scenario, we would perhaps intuitively expect that the transmission in the opposite direction, that is from the euro area to the US, would not be as large, given the relatively lower global importance of European financial markets. Interestingly, the IRFs for the US seem to suggest a significant effect even in this direction. While the pattern is again very similar to the euro area, the magnitude is considerably lower. Despite this, the median estimates stabilize at below 0,2 – this means that even though the median predictions suggest a much lower effect for the US financial stress levels than for those in the euro area, the effect is expected to be still higher than if the shock originated in the US. Although the lower bound is below the one from the European graph, worst possible cases in the scenario of a euro-originated shock are worse than for the US shock. This means that the model remarkably projects that the shock from the euro area has a more damaging effect on the financial stress levels than the US shock not only for the euro area itself but also for the US.

Again, we should note that our sample for European countries is of course much affected by the developments in the euro area following the GFI and the sovereign debt crisis. We could perhaps conclude that the model appears to show financial markets in the euro area as more fragile and more likely to trigger significant and persistent negative trends in finance compared to the US financial market. Another important takeaway may be that, while the effect of the situation in the euro area on that in the US seems (based on the FSIs) relatively smaller than in the opposite direction, it is still quite significant. The financial markets between both major economies would, based on these results, appear as highly interrelated in times of a shock stress increase.

The scenario with the shock originating in the UK might not seem as interesting as the first two since the expected impact on the FSI both in the UK and outside seems noticeably smaller. A sizeable part of the confidence interval is below the zero axis, suggesting a greater possibility of the stress levels decreasing again after the initial drop. The mean estimate for the UK is stabilized above 0 but still at a relatively low level. The pattern in this case is perhaps more chaotic than for the other two shock scenarios, however, the patterns of all the FSIs after the UK shock are overall very similar again. The effect is expected to be considerably smaller for both the euro area and the US – the median remains at positive values throughout time but is this time very close to 0. We may thus conclude that the UK would not be suggested to be as impactful (which we would perhaps expect) but there still may be a high similitude between projected patterns of the FSI development so all the model appears to view all the three indexes as highly interrelated. The financial stress levels in the UK are expected to respond to a shock from the neighboring euro area similarly to the US. The median may be overall moving slightly higher than for the US but there is no dramatic difference that would suggest the UK's FSI is affected by the euro shock much more than the US. For the shock originating in the US, the effect on the FSI is very similar to the effect on the US itself.

After taking all the effects between the three indexes in all the possible directions into account, we may again repeat that they appear highly interconnected based on the IFRs of the model. The US seems shown as being more important and influential in finance as the model suggests it is probable that increases in financial stress in the other two economies would be of almost the same magnitude as in the US after an American shock, whereas for the other two shocks, the domestic economy is clearly affected more. Interestingly, the shock in the EU is projected to be relatively more problematic and would be on average expected to cause higher financial stress increases. Developments of financial stress in the UK are on the other hand shown as having the lowest impact.

4.3 Equity Prices

To assess the effects on financial markets it is also crucial to look at the IRFs for real equity prices, that is for the other variable that could be used as a proxy for the financial sector. Whereas the FSIs are in a sense a direct proxy created specifically for this purpose, equity prices are an "actual" variable that describes only a part of the financial market, albeit a highly important one. The reactions may hence not be as direct but we surely would still expect there to be a clear suggested downturn in equity prices, otherwise the relevance of our

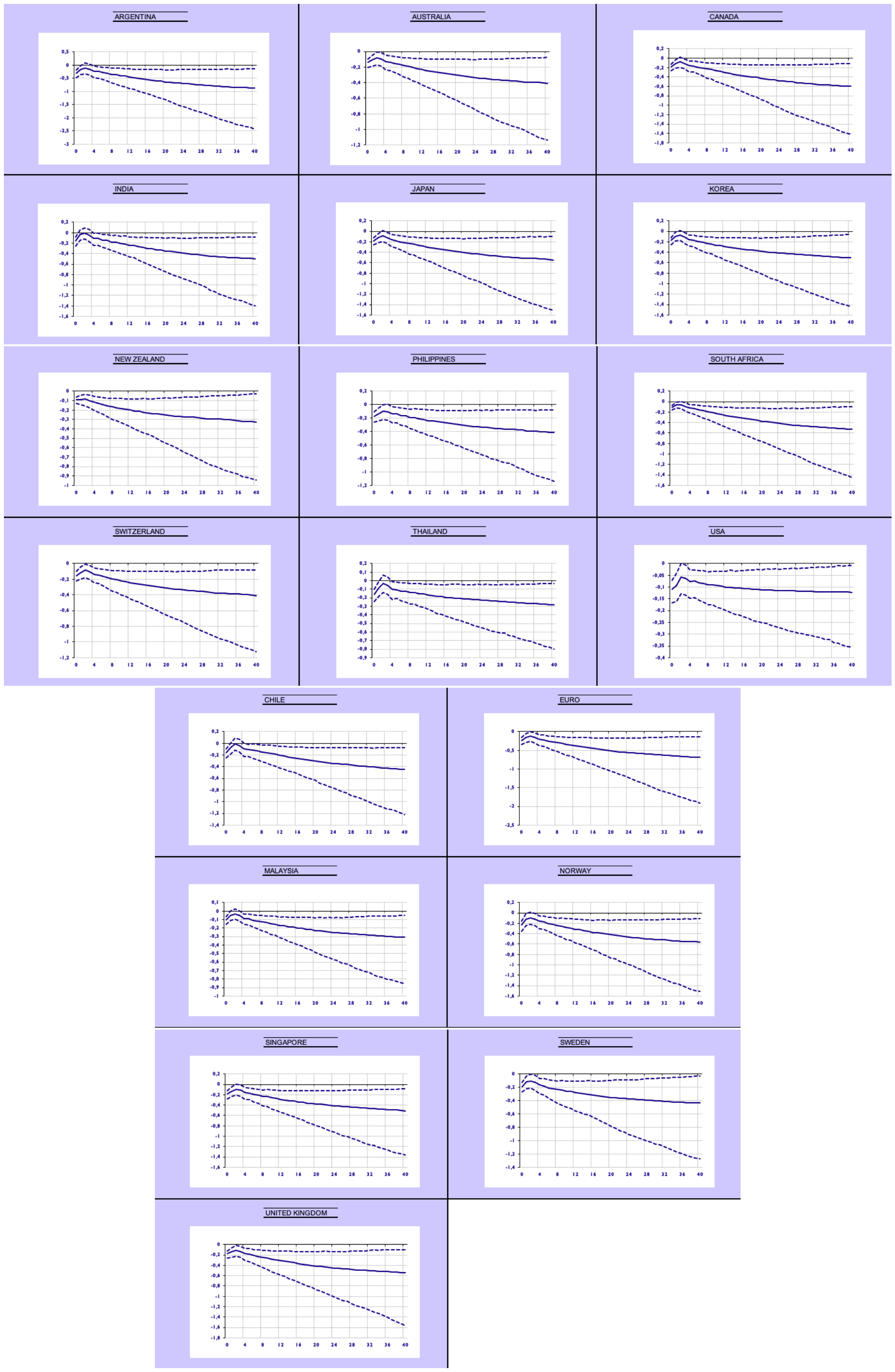

Figure 7: Response of equity prices to the euro area shock

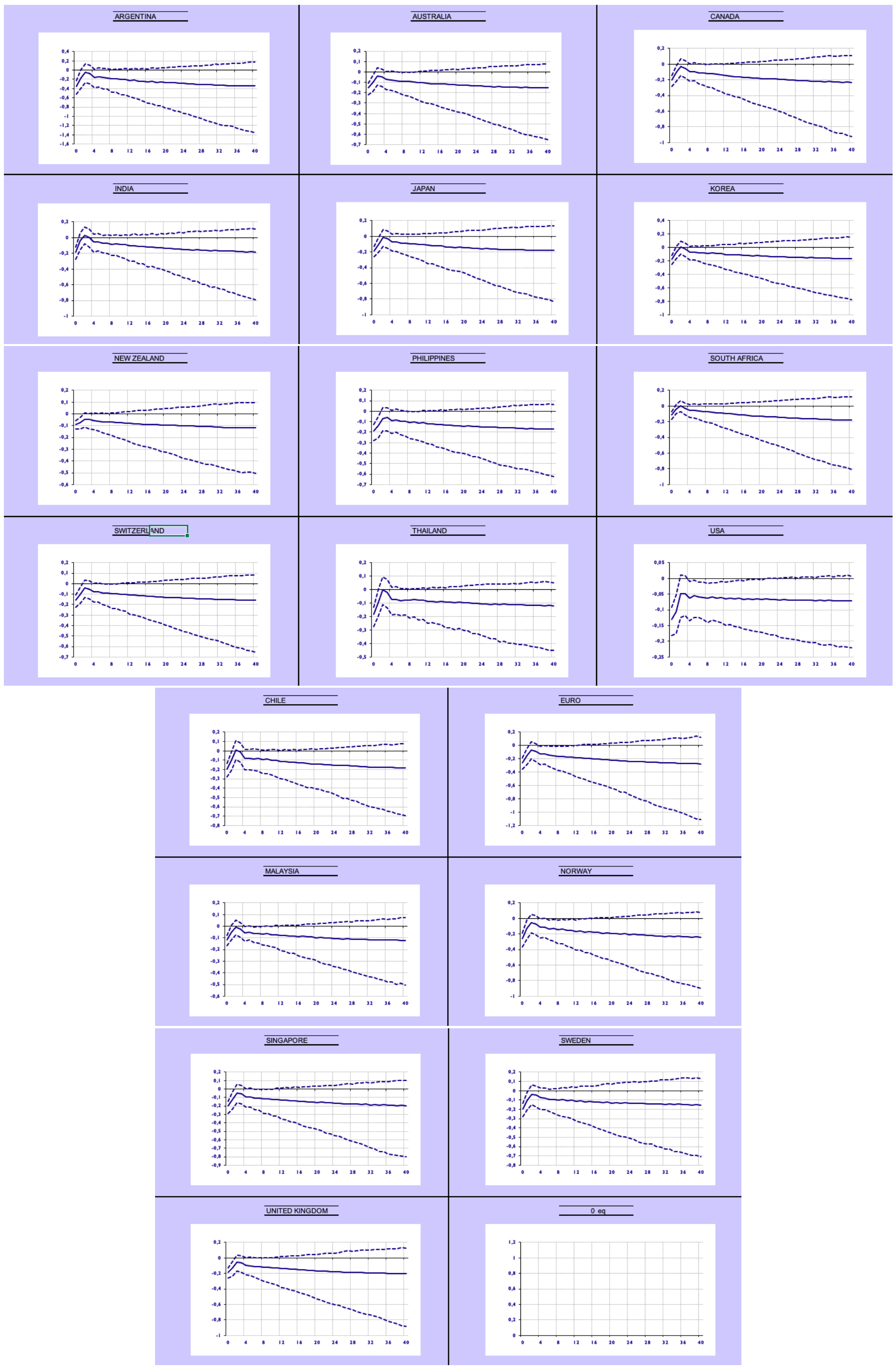

Figure 8: Response of equity prices to the US shock

whole model would be compromised.

The IRFs allow us to make some interesting points. Firstly, we may mention that the UK shock is more clearly shown as less important compared to the IRFs for the FSIs – while the confidence interval still overall suggest that decreases in equity prices across different nations would be quite probable due to the shock, the confidence intervals do not send us as clear signals. Even for the UK itself, there seems more space for no negative effect on equity prices than if the UK was affected by the other two shocks that originate abroad. The UK does not hence appear to be as important in this regard as the US or the euro area.

Between the IRFs for the shocks in the latter two, there are some notable differences. For the US shock, there seems to be a clear difference in the IRFs between the US itself and all the other countries. While the largest effect on the US itself would be intuitively expected and is also suggested by the IRFs to the FSIs, it is much more visible if we look at the projected responses of the equity prices. The confidence interval for the US is almost entirely below 0, suggesting a high likelihood of a fall in the domestic equity prices. Crucially, whereas the lower bends of all the other countries begin relatively close to the median and decrease only with time, the lower bend for the US is further below the median from the earliest periods of our forecasting, hence the negative effect seems to be expected with a greater certainty. While the median estimates in other countries are always negative and we could be overall quite certain above negative effects around the globe, there is slightly more space for no decreases left in other states (more noticeably of course in some states than the others).

If we, however, focus on the median estimate, we can observe its magnitude is in the US relatively low compared to many other countries. For the euro area, the projected median drop is for most of the forecast period approximately four times as large as in the United States. Larger median decreases are forecasted in other European economies but also in many countries in other regions of the world, for example Singapore or South Africa. We can thus conclude that although the model projects decrease in the country of the origin of the shock – the US – with more certainty, equity markets throughout seem to be generally shown as being potentially heavily influenced by the American financial sector, with the damages possibly even outgrowing those in the US. Besides the great influence of the US in global finance, we could perhaps ascribe the relatively lower median drop in equity prices in the US domestically to its markets' relative resilience, which we could presume considering the level of development and importance of the US financial markets (in this case specifically equity prices). This is nonetheless of course just a hypothesis, and we cannot make any such conclusions based on our model.

For the shock originating in the euro area, there is no such clear difference in the patterns of the IRFs as has been described for the US – for all the nations, the patterns seem very similar. This is though not the most notable difference – that would surely be the fact that across all countries the upper confidence bends are found below or just at or around zero, meaning that the model projects a financial shock in the euro area to cause decreases in equity prices practically with a certainty all across the globe. This may come as a particular surprise if we consider this was not so in the case of the shock from the dominant US economy. On the other hand, it is in line with how the FSI IFRs already revealed the euro area shock as potentially more problematic, and even for equity prices it seems that the higher damage potential of the euro shock is the key to why it seems to have more profound effects on equity markets. In the euro area itself, the projections are not only all in the negative territory but there is a visible difference between the upper band and the zero axis while the median estimates suggest a relatively high expected fall, considerably higher than if the shock was not from the domestic economy but from the US. The most interesting takeaway would then be the already-mentioned highly probable (essentially certain) negative effects in all countries in the sample with the median estimates suggesting significant decreases. Again, as for the FSI, the euro area shock is also projected to cause somewhat worse damages to the US equity markets than the shock originating directly there.

To conclude, our results do support the idea of the financial markets areas around the world being highly interconnected seems to be supported by our model – although only three scenarios have been tried and the one with the UK shock did not produce as robust results, I think we could deem the graphs of the IRFs for all the different countries still as demonstrating a high degree of interconnectedness. As the most noteworthy finding, I would consider the suggested higher negative impacts from the euro area that show it as having somewhat larger potential in causing problems worldwide even than the US. Importantly also, the idea of the financial markets in the euro area or the whole economy of the euro area having very little impact on the global markets in comparison with the US seems to be rejected by the model. The results depend of course much on the sample and the specification chosen but I believe the above-mentioned facts could still stand as interesting findings of our model.

4.4 Real GDP

Since the increase in financial stress levels negatively affects financial markets (the logic that seems to really work well in our model), they would naturally be expected to affect the whole economy. Our model captures this through the real GDP – this variable surely seems further away from the FSI than the equity prices and hence the effect may not be as clearly visible, still we would rather expect it to be at least some extent projected. Looking at the IRFs for real

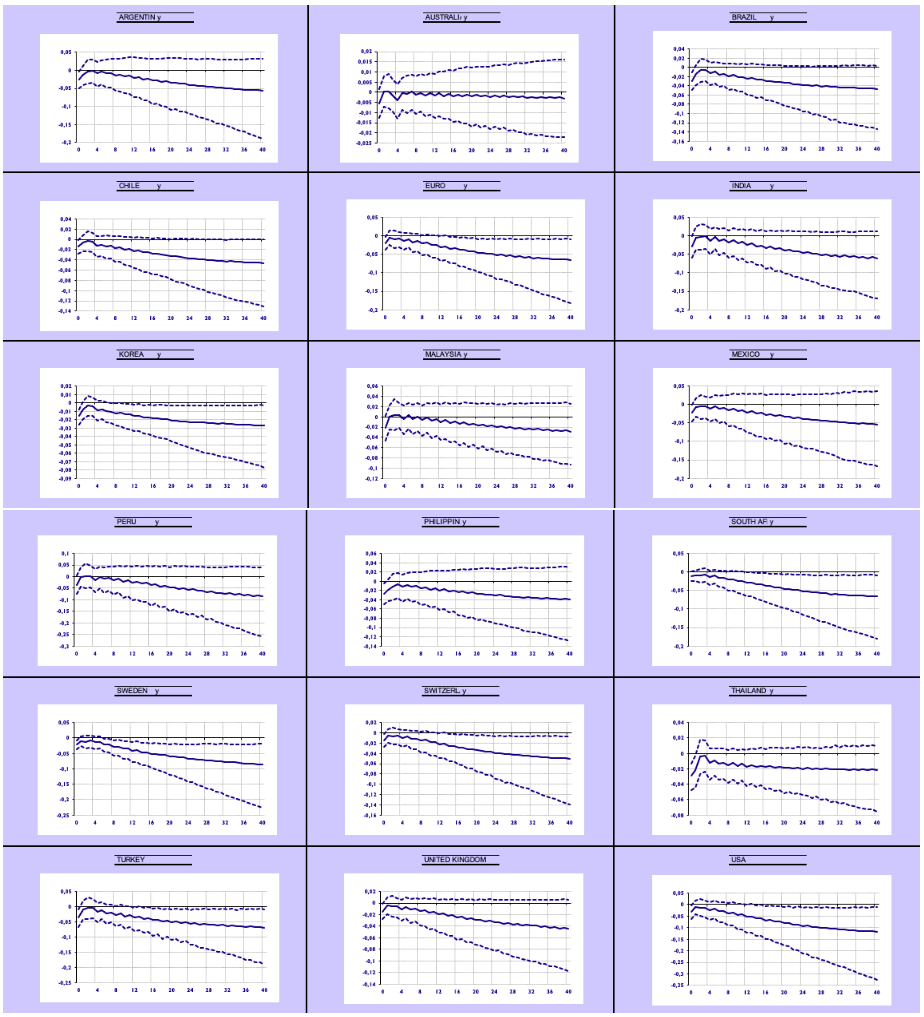

Figure 9: Response of real GDPs to the euro area shock - part 1

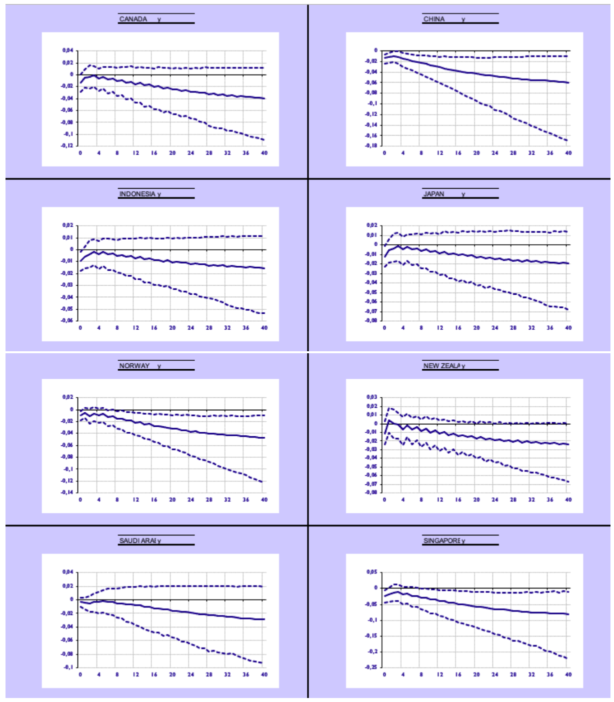

Figure 10: Response of real GDPs to the euro area shock - part 2

GDP, we can see that the model projects that the increase in financial stress in the euro area would translate into a decrease in real output in the euro area. Although the upper bend of confidence intervals allows for stagnation or very mild growth, it is shown as very probable that the financial shock would cause a long period of economic decline. Financial stress hence seems (as we would expect) to be interrelated with the GDP developments and a negative financial shock is shown as potentially a much damaging threat in the euro area.

Interestingly, the model sees the shock from the euro area as highly likely to have a prolonged negative effect on real output in many other countries in the model, including some that would perhaps not intuitively seem to be highly influenced by European financial markets. The most notable case may be China – this is the only country where the whole confidence interval is clearly below

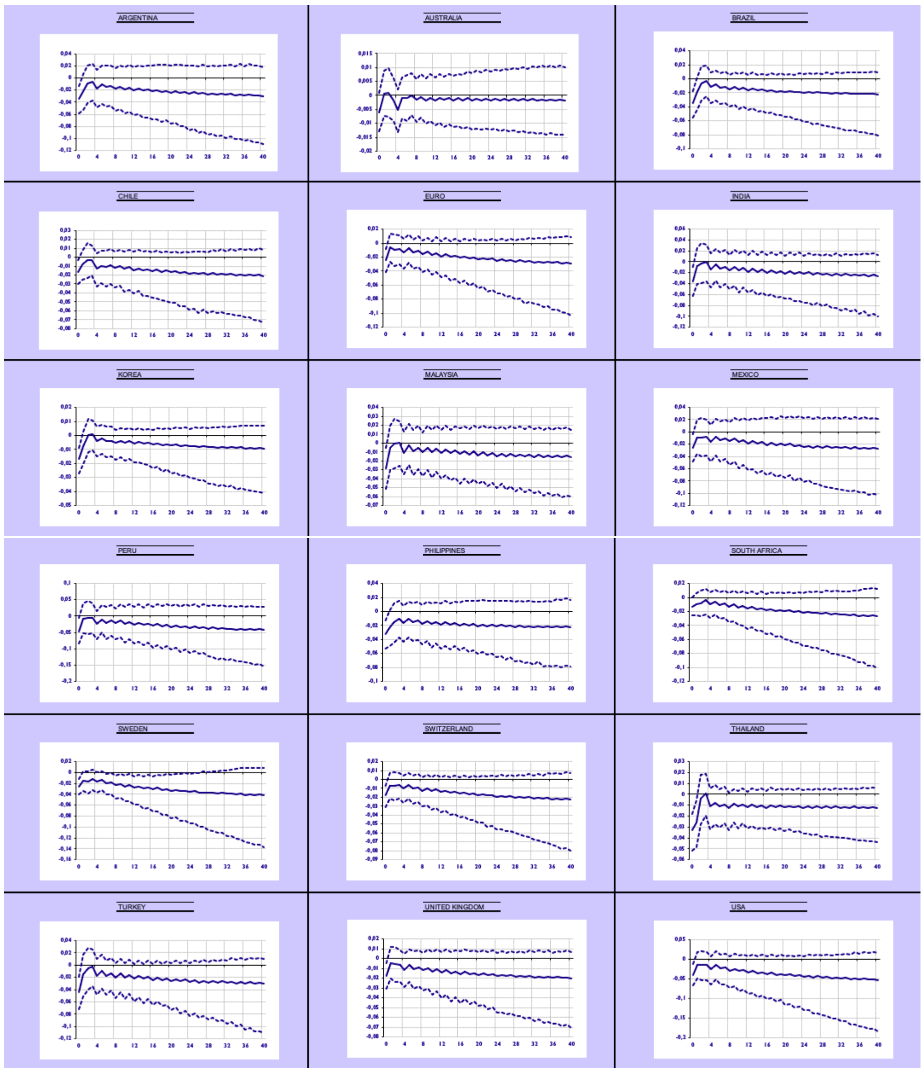

Figure 11: Response of real GDPs to the US shock - part 1

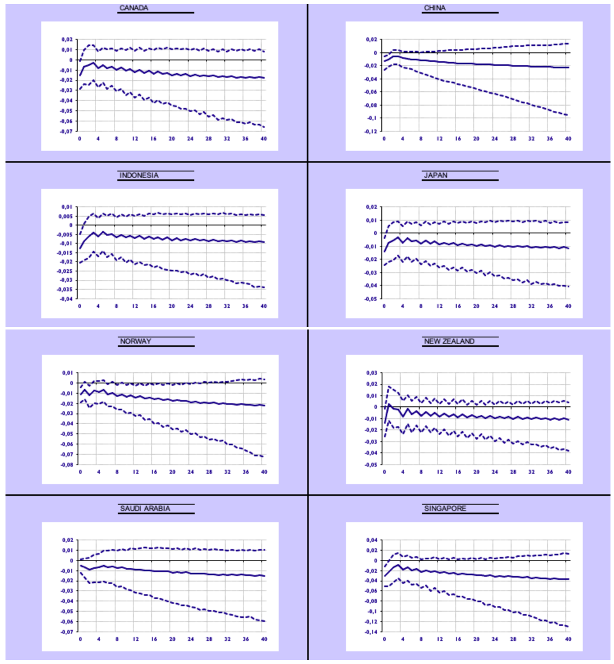

Figure 12: Response of real GDPs to the US shock - part 2

zero, meaning the model is quite certain about a negative effect on Chinese economy, even more so than for the euro economy itself. These IFRs for China give us noticeably clearer negative projections than the IFRs for South Korea. The projections for Japan then seem even much less clear – although the median estimate still suggests a negative effect on the GDP, the confidence intervals leave much more space in this case for the absence of an output drop and the median values are above those for China (i. e. a smaller decrease would be expected). We can thus conclude that one of the more interesting and certainly less predictable takeaways of the shock simulation might be this visibly larger effect that the financial shock from the euro area should have on China than on the other two large East Asian economies, particularly Japan.

The shock to the European FSI is shown also as very likely to cause a GDP decrease in the US. This seems in line with the already discussed negative impact on the US financial stress levels. Euro area's EEA neighbors Sweden and Switzerland are overall projected to be significantly affected as well. Another neighbor of the currency union, the UK, seems to be affected slightly less, even a bit less so than the US. For certain countries, the effects on real GDP following a financial shock in the euro area seem more dubious and more different from the euro area, perhaps most so for Argentina, Australia, or Peru. Still, the medians are below 0 for all countries of the model and the patterns of the IRFs are close to the ones in the euro area itself in the majority of the states. We could perhaps hence be inclined to see a high interconnectedness and relatively significant influence of financial markets in the euro area overall.

The results for the US shock might in the light of the results for the European shock come as surprising. The reason for this is that the US shock is generally not projected to cause as much damage to national GDPs as the originating in the euro area. The results for the FSIs might already be a hint of this, as they already showed the US shock as being expected to cause less financial distress. This seems to translate rather strongly to the effects on the GDP – the confidence interval of the IRFS for the US GDP itself (including the median life) is pushed slightly but more upwards compared to the case of the euro shock. Still, we could intuitively expect other countries to copy the US IFRs more closely due to its dominant role in finance and thus the negative effects to be more pronounced. This, however, does not seem to be the case. As has been said, the results overall suggest lower expected decreases in the GDPs.

Looking at the graph for the euro area, which interests us the most, we can see a very similar projected development as in the US. This is so also for other countries neighboring the currency union. We may hence (just like for financial stress) conclude that the US shock would be expected to affect the GDP of the euro area similarly as the US itself, however, it seems as less of a problem according to the results than a shock originating directly in the euro area. Interestingly, the IRFs for American neighbors Canada and Mexico or also for the traditionally closely related United Kingdom diverge more from the US ones more and allow a greater space for the possibility of there being no GDP downturns resulting from the shock – the predicted behavior is simply visibly closer to the US for the euro area and its neighbors despite the greater geographic and non-geographic distance. Just as for the European shock, the reactions in China appear to show stronger negative effects than in Japan and South Korea, although GDP downturns are not expected with certainty as was the case for the euro area shock. Countries whose IRFs for the GDPs follow the US ones least are again Australia or Thailand. The patterns of the IRFs are very similar to the ones for the euro shock as well.

We may conclude that the results for GDPs seem to complement those for the FSIs. The most notable takeaway is perhaps that the shock originating in the euro area is shown as actually somewhat more problematic than the hypothetical US shock – it would be projected to be more likely to cause higher decreases even for the real economies of the countries in the sample.

4.5 Inflation

For inflation, we would not expect the IRFs to allow us to make any clear conclusions. Generally speaking, this is indeed so for all the shock scenarios – while the median estimates tend to suggest an initial shock increase, they then remain around 0 throughout the forecast period, with the upper and lower confidence bends being broadly speaking in similar distances from the median. What is clearly visible is the variety in widths of the confidence. In Argentina or Turkey, for example, both countries with a history of rather stark changes in inflation, the interval is very wide. On the other hand, for numerous countries,

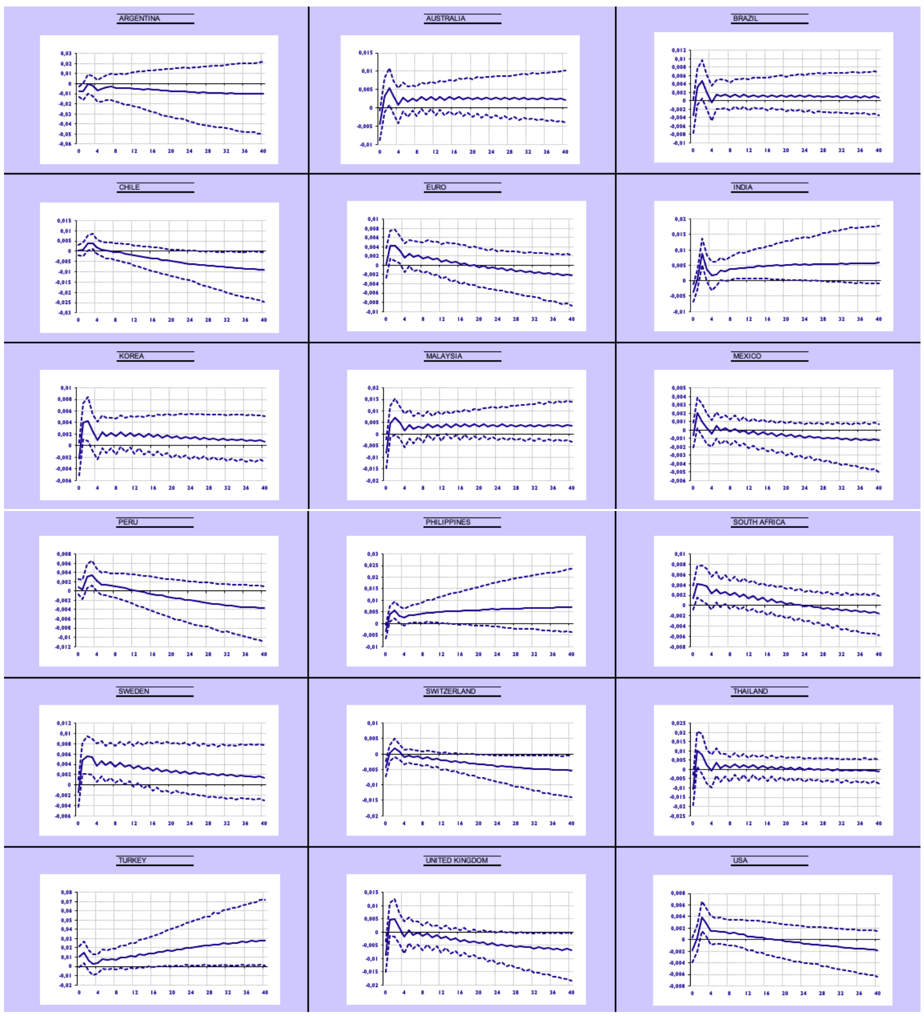

Figure 13: Response of inflation rates to the euro area shock - part 1

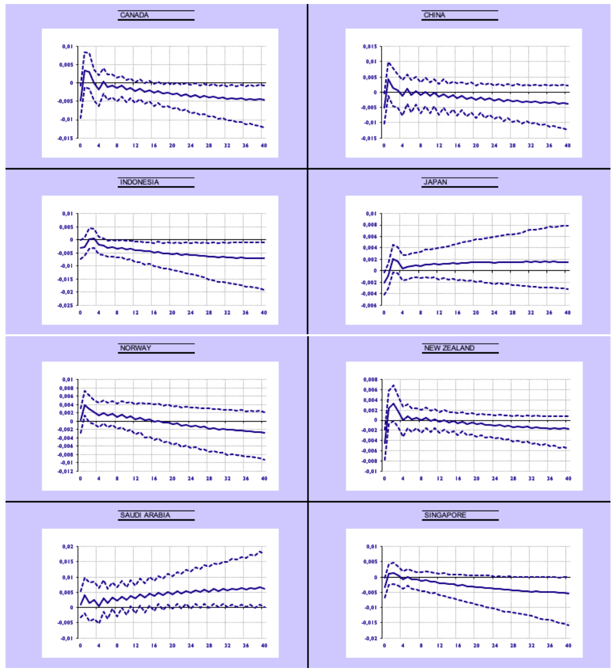

Figure 14: Response of inflation rates to the euro area shock - part 2

for example New Zealand or Switzerland, it remains relatively narrow. The IRFs are in these cases still inconclusive about possible effects of the shock on inflation but they demonstrate that the model is certain about inflation in these countries not fluctuating wildly, hence viewing them as stable in this regard. While this could perhaps also be generally deemed a conclusion worth further commentary, it is of no interest to us given the aim of the thesis.

What we may nonetheless put some attention to is how in certain cases, the confidence interval appears somewhat more pushed downwards and more clearly having a downwards trend, suggesting that few quarters after the shock occurs, deflationary pressures could be more likely or that at least a higher inflation would not be as likely. Although it is not easy to come up with more conclusive presumptions about how the shock could impact inflation, or to assess whether there would be any impact at all, we might perhaps still be inclined to expect more downward pressures on inflation, as the financial shocks seem to be expected to have a potential to cause an economic downturn and in times of economic crisis we could presume a decreased level of consumption and in turn also a low level of inflation to occur. This has been the case during the 2007 crisis – as has been already discussed, unconventional measures such as shadow rates were implemented precisely to counter deflationary fears and to help increase consumption. The results may hence reflect this to a degree – the above-described feature of some of the IRFs is particularly for the EU shock, (which, as has been discussed, could be viewed as potentially most damaging). However, it still holds overall that the results on inflation are simply not conclusive at all and give us much less usable information than the results on the variables discussed before – again, this should not come as a surprise.

4.6 Exchange Rates

Similarly, we would not expect decisive results for real exchange rates. Again, it seems rather challenging to assess the possible effects of a financial shock and since we already know based on the results for inflation that it is unclear how inflation rates in different countries would develop, we would expect there to be much certainty regarding how the exchange rates between the corresponding currencies develop. The results are in line with this logic clearly unclear throughout our sample. The confidence bends appear to be generally moving significantly further away from the median prediction with each quarter of the forecast period. Argentina may still be a notably different case, as the IRFs seem in this case skewed towards the positive response. For the euro and US shock simulations, the whole confidence interval appears to be in the positive territory, meaning that an increase in the real exchange rate and depreciation would be highly probable according to the model. Again, this may be rather

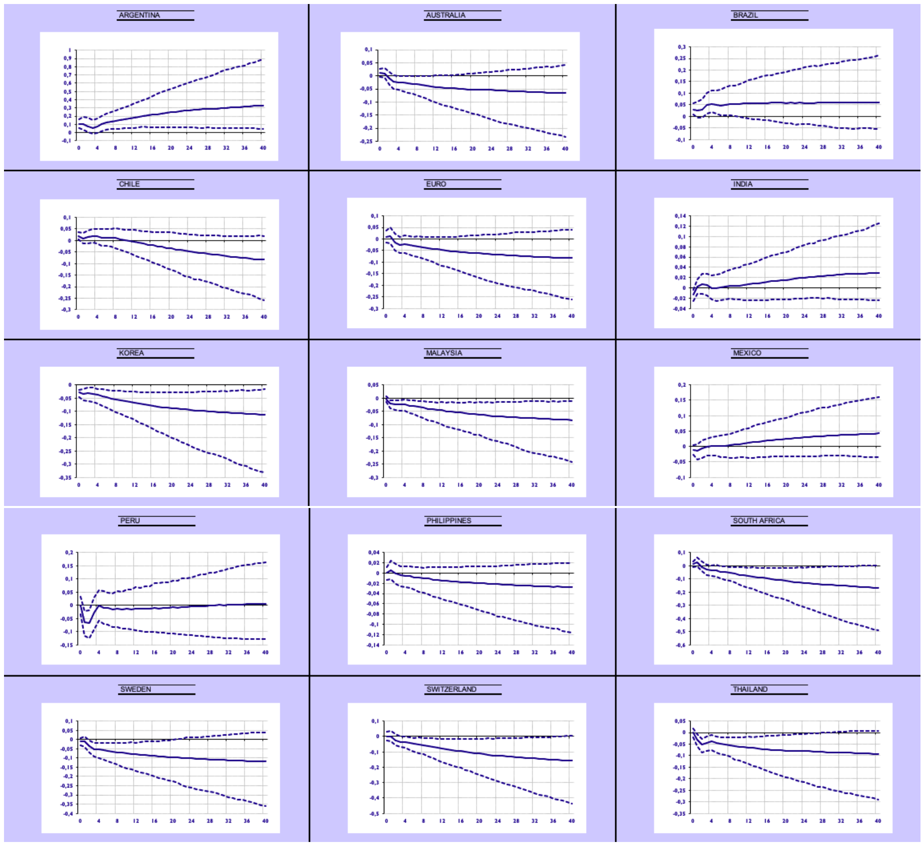

Figure 15: Response of exchange rates to the euro area shock - part 1

due to the particularity of Argentine's monetary history and so in the end not of much interest for our research.

Contrary to Argentina, most other countries seem to have their confidence intervals somewhat skewed towards the negative numbers. Interestingly, this is much more visible for the euro shock scenario. In this case, the confidence intervals for several countries are actually located wholly above the zero axis, allowing us to conclude that the model would expect these national currencies to appreciate. For the euro area itself, the results suggest that appreciation could likely occur in response to the shock although in this case the upper confidence band still allows to some extent for an increase in the real exchange rate. We

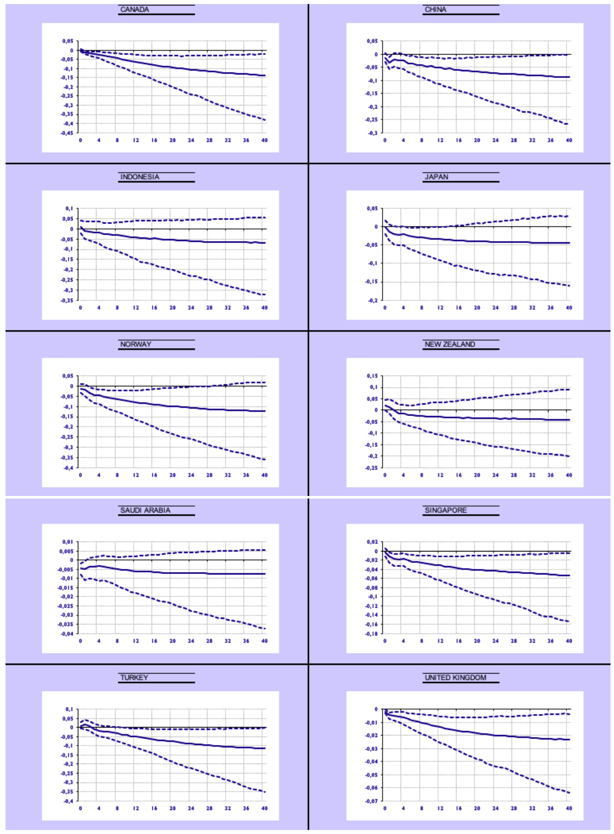

Figure 16: Response of exchange rates to the euro area shock - part 2

could perhaps presume that this is due to the euro shock being shown as having particularly notable potential for negative effects, however, we should still be very cautious due to the lack of clarity regarding the link between the FSI and the exchange rates and the generally highly chaotic IFRs if we consider all the three scenarios.

4.7 Interest Rates

For short-term rates, we would perhaps not be surprised to find even more inconclusive results since there could be much ambiguity regarding the relationship between this variable and the FSI. The results are in general indeed much

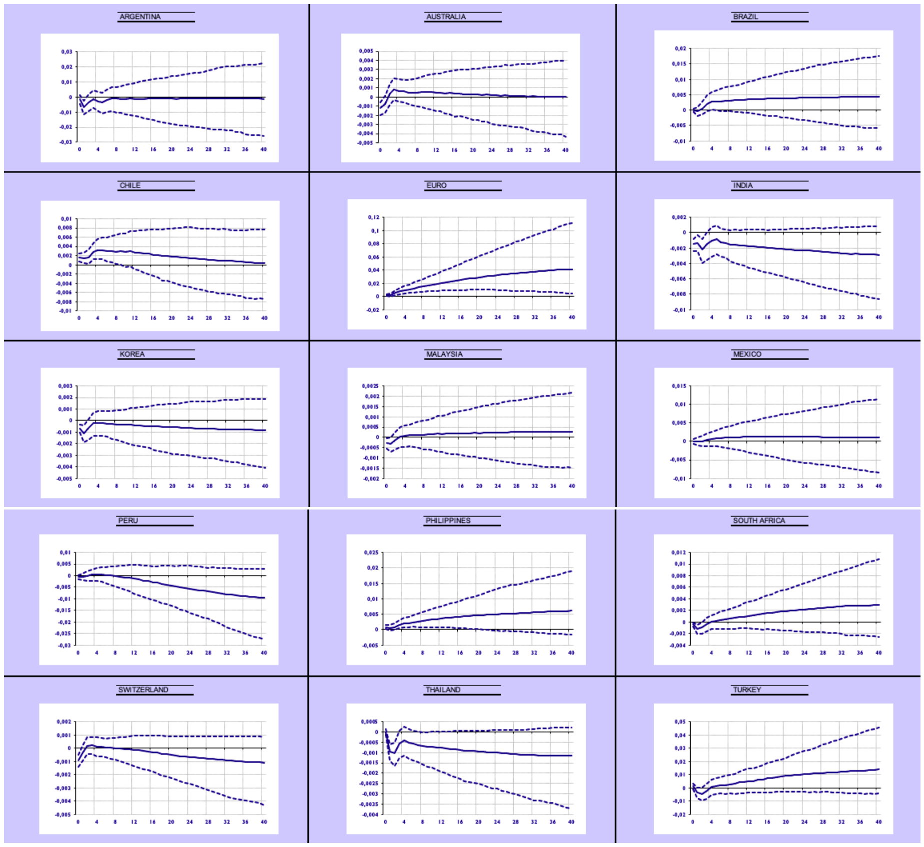

Figure 17: Response of short-term rates to the euro area shock - part 1

ambiguous and do not allow us to draw anything from them with the confidence intervals being spread out through both the negative and positive part of the graph. There are, however, few exceptions. The most notable may be the IRF for the euro area after both the euro and the US shock (and to some degree also after the UK shock) – it seems to suggest with a great degree of certainty an increase in the nominal rates, which is projected to increase in magnitude with time. This could make us worried because the euro area has shadow rates included in the short-term rates data, so we might perhaps think this causes some distortion. We would nonetheless expect the distortion to go maybe rather in the opposite direction – if there was a clear reaction of the interest rates, we

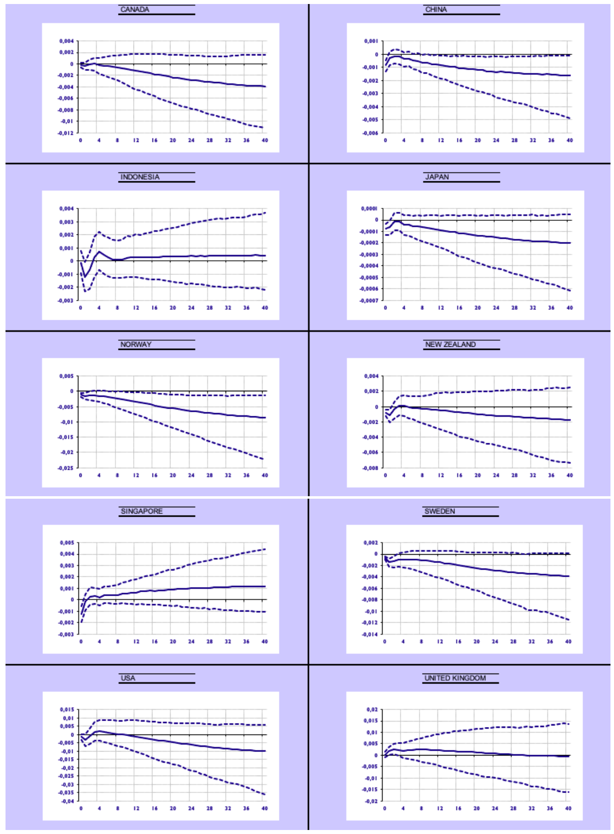

Figure 18: Response of short-term rates to the euro area shock - part 2

would rather expect it to be a decrease, as it was the financial crisis that originally brought interest rates to the unconventionally low numbers – this could be even more pronounced with the data that capture the era of negative shadow rates. On the other hand, we have to remember that the rates remained negative for a long period even where the crisis was gone and then during the COVID pandemic, even though the financial sector was no longer subjected to as much stress as just after the breakout of the crisis. Furthermore, we can also expect that the financial sector is not in as much stress thanks to the possibility to lend at extremely low (or in actuality even negative) rates. These factors perhaps might have caused the model to find some correlation between financial stress and interest rates.

However, for the US or the UK, there are no such results, and their data include shadow rates as well. Relatively similar behavior of the IRFs as for the euro area can be observed for Turkey. On the other hand, an almost inverse pattern to the euro area – that is an increase in rates increasing over time – is predicted for example for Norway or Sweden. As has been already said, elsewhere the results tend to be much more inconclusive. Hence, I think we could perhaps consider the cases where it is otherwise as a few cases where the model simply somehow forecasted a clear direction in the development of the short rates, but we still cannot easily draw any general solutions from this.

4.8 Shadow Rates

In evaluating our model, it is also important to investigate whether the addition of shadow rates causes any noticeable changes in the results. As has already been discussed in the section concerning the data, the estimated values of the shadow rates have been used as inputs for the euro area, the US, and the UK, during certain parts of the sample period instead of the conventional values provided by the default GVAR dataset by Mohaddes and Raissi (2024). Since the modified data points represent only a very small fraction of the whole dataset used by the model, we would naturally not be inclined to expect any major changes or a complete reversal of the key results to be caused by the inclusion of the shadow rates. We would ideally nonetheless like to see at least some changes in the IRFs based on the shadow rates' inclusion, since this methodological decision would otherwise prove practically meaningless.

To assess this, the shock simulations have been run without the shadow rates, that is with the default short-term rates data for the whole sample, but with the very same specification as the base model of the thesis. There are

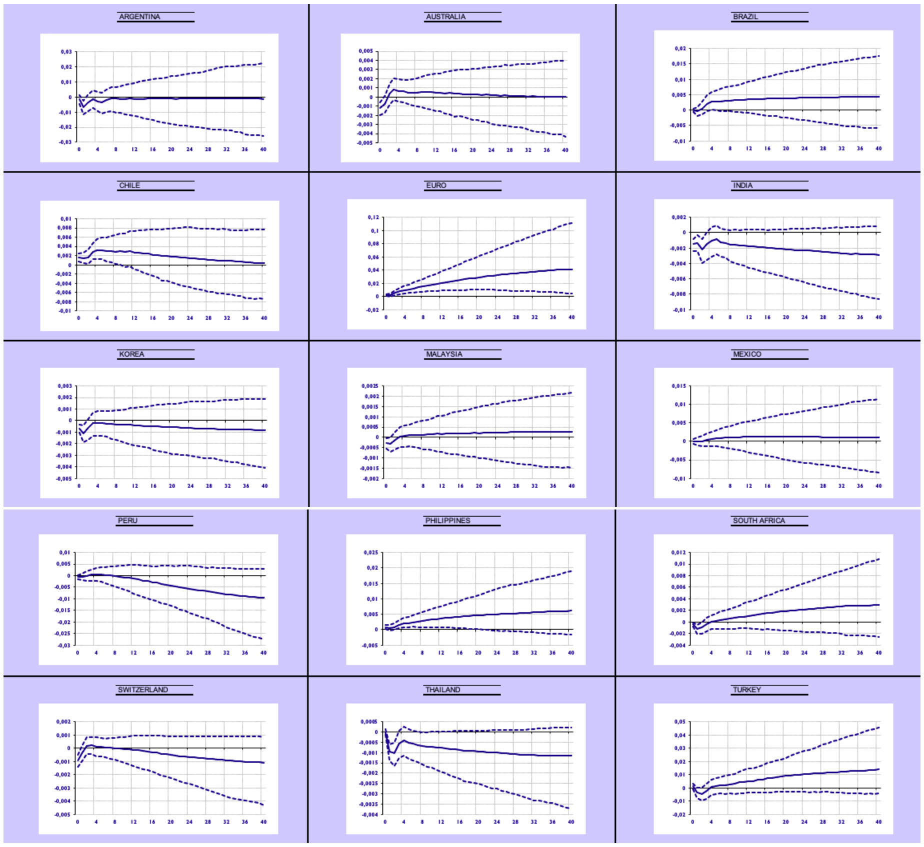

Figure 19: Some of the responses of short-term rates to the euro area shock under the no shadow rates alternative

indeed clear differences in the IRFs in these cases. The most notable differences can be found as would be expected in the short-term rates projections. As has been already established in the discussion of the results, this is not the variable from which could draw any crucial conclusion, which could be applied broadly across the countries in our sample. The IRFs may be more chaotic in this case but still, the differences if the shadow rates are not included are rather stark. Most importantly, there is a major difference in the euro area predictions, which are of the greatest interest to us. This is one of the few cases where the IRFs are clear about the expected direction of the change, as our model with the shadow rates suggests that there should be an increase in the rates, with the upper confidence band allowing even for a relatively large increase. Essentially, the complete opposite is predicted if we drop the shadow rates for the euro area (and for the other two cases where they are available) – the model now suggests with a great degree of certainty that the rates would fall with the lower confidence band allowing even for a large decrease. This result may come as particularly interesting if we consider that the inclusion of the shadow rates in the sample means that unconventional negative values are attained in the sample for a longer period following the financial crisis – yet it is the model that covers this behavior that predicts an increase in the rates.

The main conclusions regarding the key variables would not necessarily be different without the shadow rate but the IRFs' curves are overall visibly different also for other variables. Notably, for example, the lower confidence bend of the predictions for equity prices and real GDPs in the model with the shadow rates mostly finds itself relatively close to the median estimate at the beginning of the forecast period but with time passing moves significantly further away. There is no such pattern in the projections of the model with the default rates, as the confidence bands around the median estimate tend to remain at a much more stable distance from the median. Conversely, the upper confidence bands for the FSIs grow with time allowing for a greater upward variation in the predicted increases of financial stress in our model with the shadow rates included and this is not the case if they are omitted. The main conclusions such as the predicted drops in equity prices or real GDPs across the countries would not be as strong in numerous cases under the no shadow rates alternative. There are generally also noticeably large differences in the exact shapes of the curves and the exact values of the underlying predicted values of changes in our variables.

It shall also be noted that the bootstrap estimation process runs more smoothly if the shadow rates are omitted – the instances where the model turns unstable during a particular bootstrap estimation (and so this estimation is interrupted and the next bootstrap estimation starts) are considerably less frequent, essentially quite rare if the basic short-term rates data are used in the whole sample. The inclusion of the shadow rates, which were during the periods used mostly attaining the highly unconventional negative values, therefore appears to hurt to some extent the model's stability. The model as it was used in the thesis and its results may hence be somewhat more problematic from this point of view, even if the shadow rates modifications should provide a better approximation of the short-term rates' actual behavior and at the same time also some differentiation from the past research.

The most important takeaway from this comparison is nonetheless the fact that there are non-negligible differences caused by the addition of the shadow rates. The opposing predictions for the response of short-term rates in the euro area could in my view be taken as one of the most notable conclusions of the thesis, as they show how greatly different the handling of the shadow rates by the model can be with this seemingly small modification. The differences that could be found also for other variables further support the potential importance of covering the shadow rates in modeling.

4.9 Summary and Comparison with Past Research

Past research has generally been supportive of the idea of a fast and significant spread of financial shock from the US to other economies globally. It has been one of the conclusions already of the seminal paper by Dees, Mauro, Pesaran, and Smith (2007), and further research, for example by Sgherri and Galesi (2009), Chudik and Fratzscher (2011), or Eickmeier and Ng (2011), has agreed. The model of this thesis also reaffirms this conclusion – the shock from the US transmits internationally and can in the euro area cause negative consequences of the same scale as in the US. This result that could perhaps be a priori expected, given the generally understood crucial role of the US financial markets, is hence certainly not surprising or new in any way. It can still be noted though that Eickmeier and Ng (2011) for instance find the transmission to Japan to be even faster than to the euro area whereas in our case the results are clearly less conclusive for Japan than for the transatlantic transmission channel.

What may be deemed more interesting than the results regarding the US shock are the results for the shock originating in the euro area. The transmission in this direction has overall not been as researched. While Menon and Ng (2013) show that the financial shock from the European currency union could affect Southeast Asia, Eickmer and Ng (2011) have found the euro area shocks to not have a major international impact, particularly in comparison with the US. Our results strongly support the idea of shocks in financial markets in the euro area significantly affecting economies around the globe. Most interestingly, and perhaps quite surprisingly, the model shows in our case that the euro shock's potential for damages is even larger than for the US and this is so not only in the euro area itself but in many other economies as well. In particular, the euro area shock could affect financial stress levels in the US even more than a shock that would originate directly there. This is not to say that our model finds the transmission from the euro area to be more significant than from the US – the magnitude of negative consequences in the economy of the origin of the shock is estimated to be greater for the euro shock scenario, and hence if the shock transmits, the consequences to financial markets are relatively large. Our model perhaps views thus financial markets in the euro area as more fragile in a sense and more susceptible to a larger financial crisis. Nonetheless, the thesis' results are in favor of the rapid shock transmission also from the euro area.

Importantly, our results suggest that the shocks could have consequences beyond finance and affect whole economies of other nations, having a potential to cause drops in GDP. This fact further stresses the significance of the shocks, whether originating in the US or in the euro area, projected by the model of this thesis. The results in our case hence rather starkly support the idea of a high degree of interconnectedness and global significance not only of the US but also of the euro area's financial markets.

Secondarily, the thesis also includes results on the UK shock scenario and despite the fact that these results are not as strong as those for the euro area or the US, it overall still seems to be suggested by the model that the shock originating in the UK could have a global significance as well. Even though the UK is amongst the largest and most impactful economies, its size compared to the US, or the euro area economy is of course relatively small. The fact that the model suggests the shock to financial markets in the UK would be likely to cause some negative effects in different countries worldwide could hence be seen as further support for the idea of a high degree of interconnectedness of global financial markets in general, at least when it comes to the transmission of shocks.

While the difference in the results regarding the short-term rates for the euro area makes it difficult to conclude clearly on this matter, it shows how the inclusion of the shadow rates may change the results. Since we are not particularly focused on monetary policy and the behavior of interest rates in our case, we may perhaps remain more cautious in this regard, as a more detailed investigation of the effect of the shadow rates and perhaps a more sophisticated inclusion of the rates in the data sample would be beneficial. Nonetheless, the difference in the predictions is simply present in the result and this may still be deemed a noteworthy result.

There are also numerous others more specific results brought about by the thesis' model that could be found interesting. Perhaps most notable may be the results regarding China, which could also be perhaps deemed somewhat novel compared to the conclusions of similar research. Although unlike for other countries in the sample a variable that could proxy financial markets in China is not included in the model, the results for China's real GDP still allow us to conclude that the country would be predicted to be negatively affected as well. The model in the euro shock scenario projects practically with a certainty that there would be some decrease in the Chinese GDP. The results are seemingly quite strong even compared to those for the euro GDP. Again, this appears to further support the potential of the euro area shock to cause significant global harm, as the consequences are clearly suggested even for Asia's largest economy, which despite having become a major global player definitely does not intuitively seem as interlinked with the euro area's financial markets as the US. This conclusion regarding the suggested relatively high impact of the euro shock, which has already been mentioned several times, may perhaps be the most notable takeaway from the thesis' results.

5 Conclusion

In this thesis, I tried to study the transmission of financial shocks using the GVAR modeling framework. The ECB indicators covering financial stress levels in the euro area, the US, and the UK, were included as global variable in the model and used as the origins of the shocks simulated. For these three countries, the shadow rates estimates were included in the short-term rates data instead of the standard values during the years of unconventional monetary policy.

The model overall suggests that financial shocks may significantly and rapidly transmit around the globe, being in this regard generally in line with the conclusions of past research. The transatlantic transmission channel appears to be shown as particularly significant, with the impacts of a financial shock from the US projected to affect the euro area economy with essentially almost the same magnitude as the US. Even though the UK shock is shown as significantly less significant when compared to the other two shock scenarios, the negative effects still appear to be relatively likely, further supporting the idea of a high degree of interconnectedness when it comes to the spread of problems from the finance sector across countries.

Interestingly, our model projects that the spread of the contagion in the euro area shock scenario could be more damaging to many other economies than if the shock's origin was in the US. It is even possible according to the model's results that a shock from the other side of the Atlantic could pose a slightly larger threat to the financial markets and the whole economy of the US than a domestic shock. Based on these results, the euro area could perhaps be deemed as a more fragile economy that is potentially more susceptible to large-scale financial crises than the US. Many other more specific interesting results are arrived at are in the thesis, for example the projected significant effect of shocks from both the euro area or the US on China, especially when compared to Japan.

The inclusion of the shadow rates in the model cause some alterations in the results. Most notably, the forecasted response of the euro area short-term rate to the shock is essentially reversed completely due to the presence of the shadow rates. The thesis hence appears to suggest it may be worth considering accounting for shadow rates in research even for example in international macroeconomic models such as the GVAR model. Shadow rates may then be naturally expected to have a particularly large impact when conducting empirical research focused on monetary policy and interest rates.

Despite the fact that international macroeconomic relations are researched very frequently and the GVAR model in particular has been often used for this purpose sine its inception, there still seems to be much space left for further research similar in some ways to that of this thesis. While this work was solely focused on financial shocks and put an emphasis on the euro area, the GVAR model offers much wider possibilities. In fact, even the output generated during the deployment of our model has not been wholly covered at all in this thesis, as only the results relevant for its aims were spoken of in detail. Crucially, the conclusions drawn are understandably reliant to a great degree on the specification of the model I have decided to opt for in thesis. Numerous further modifications to the model would be possible, some of which could perhaps make it more sophisticated and allow for a greater insight into the topic.

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A Appendix: Additional IRFs

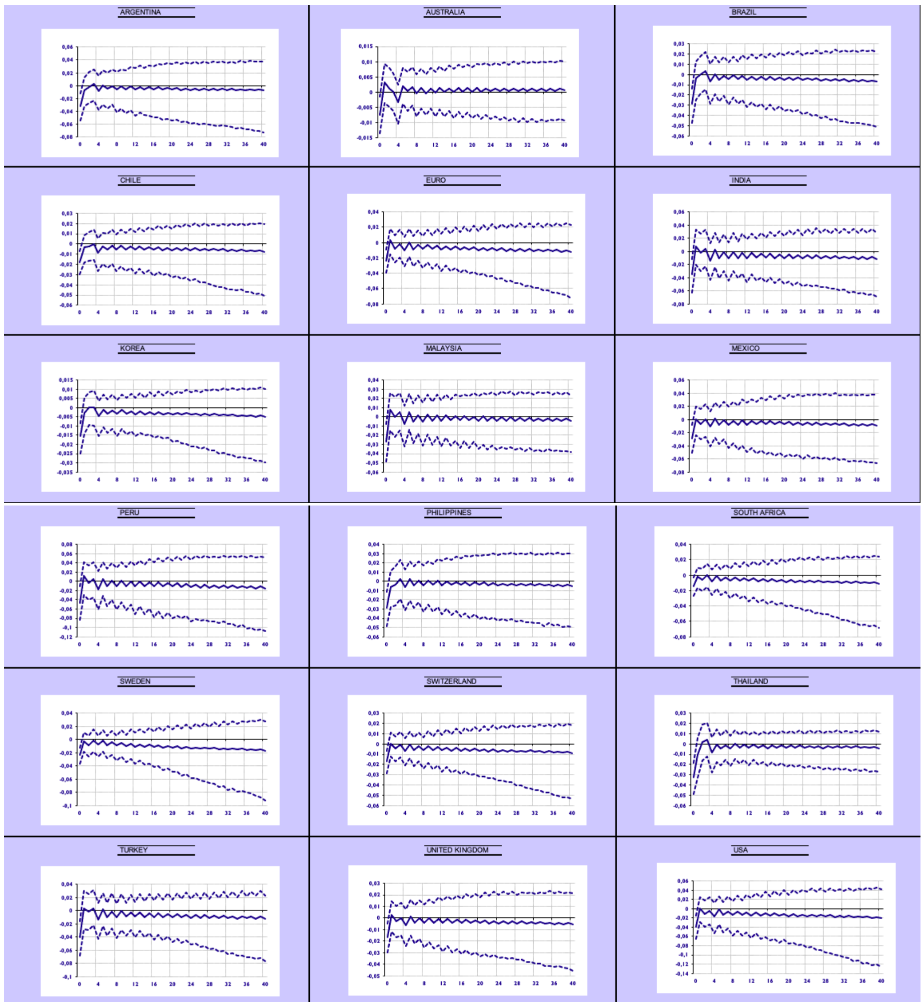

Figure 20: Response of GDPs to the UK shock - part 1

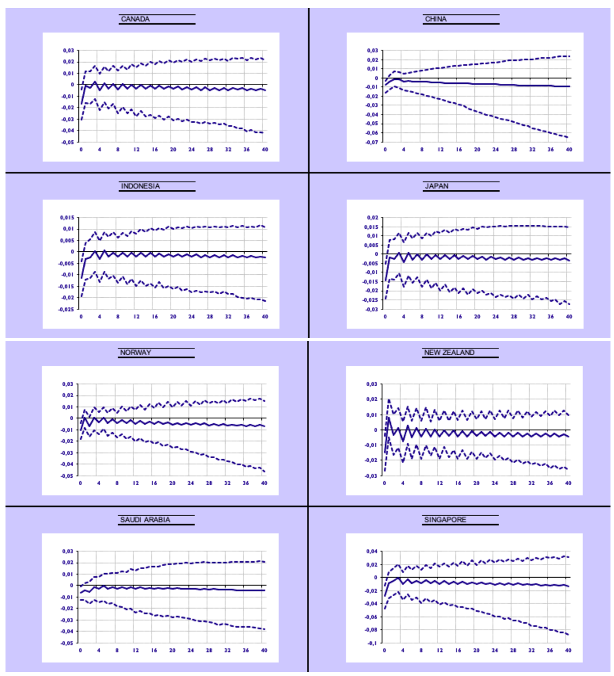

Figure 21: Response of GDPs to the UK shock - part 2

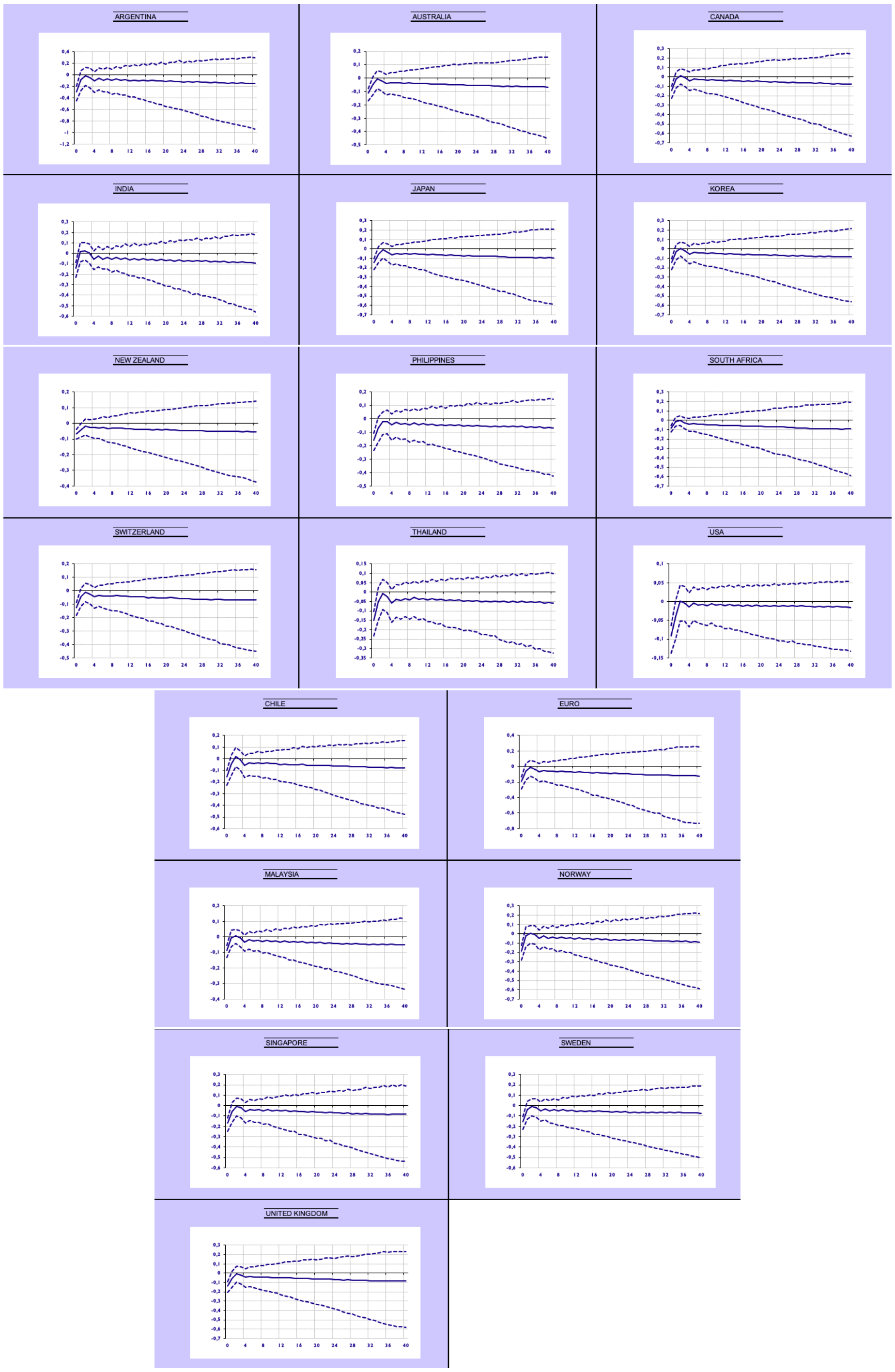

Figure 22: Response of equity prices to the UK shock

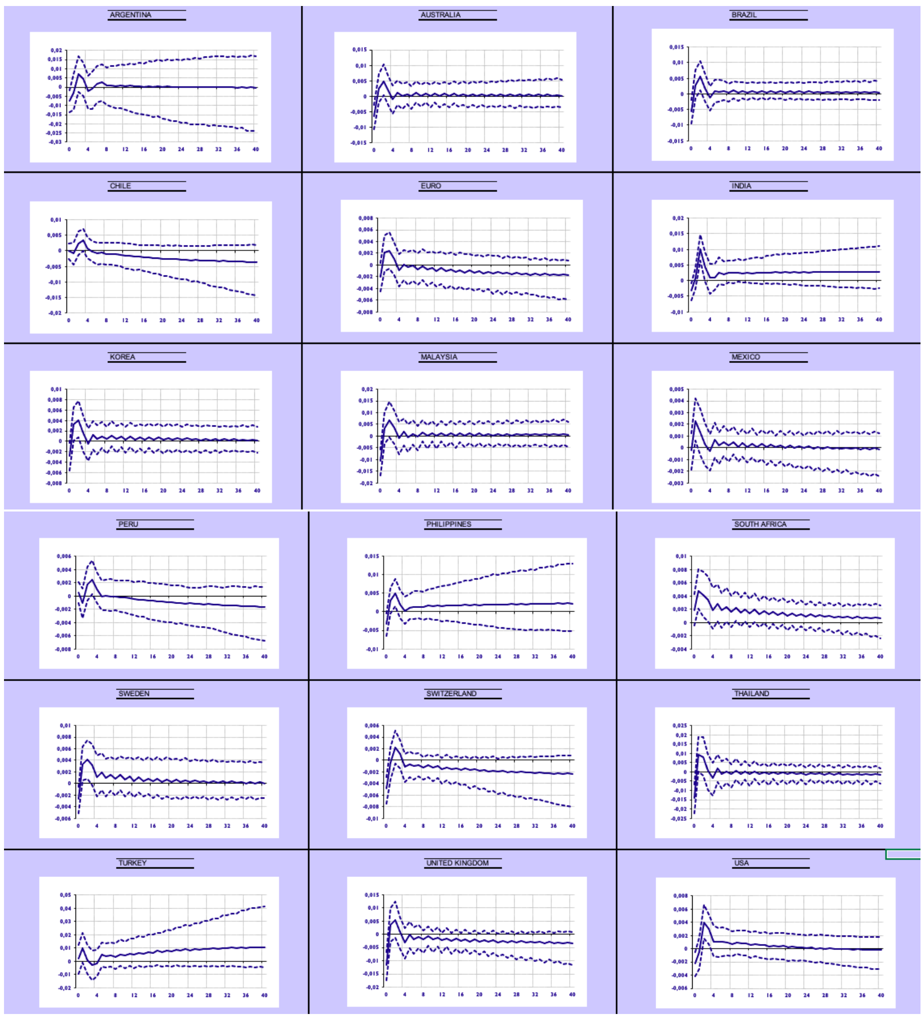

Figure 23: Response of inflation rates to the US shock - part 1

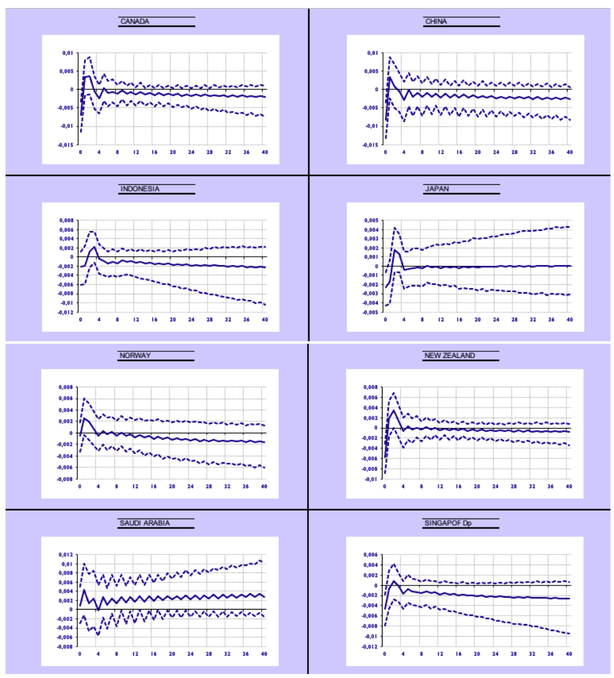

Figure 24: Response of inflation rates to the US shock - part 2

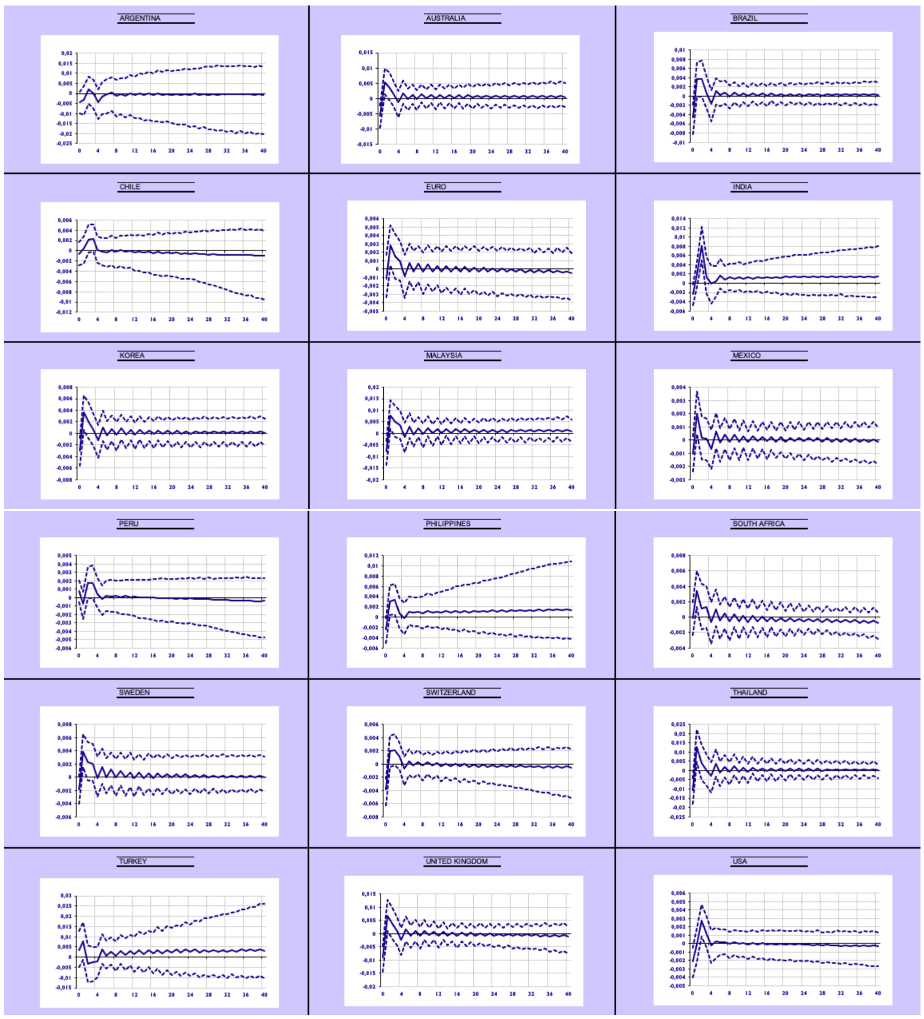

Figure 25: Response of inflation rates to the UK shock - part 1

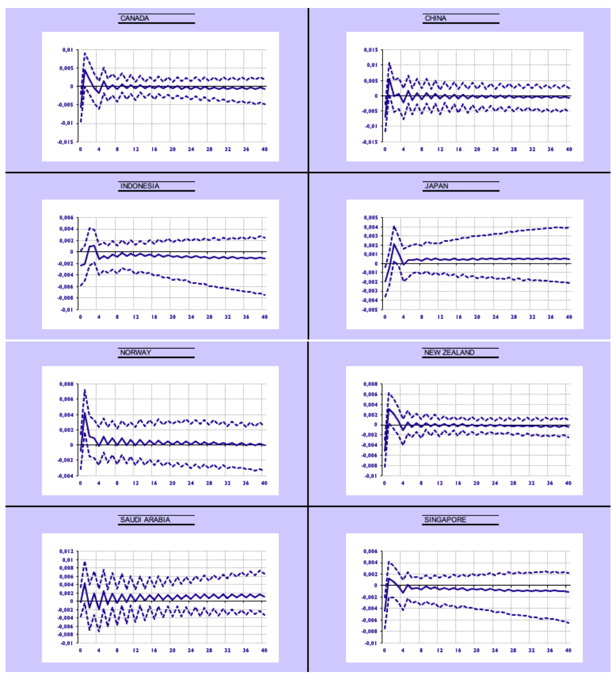

Figure 26: Response of inflation rates to the UK shock - part 2

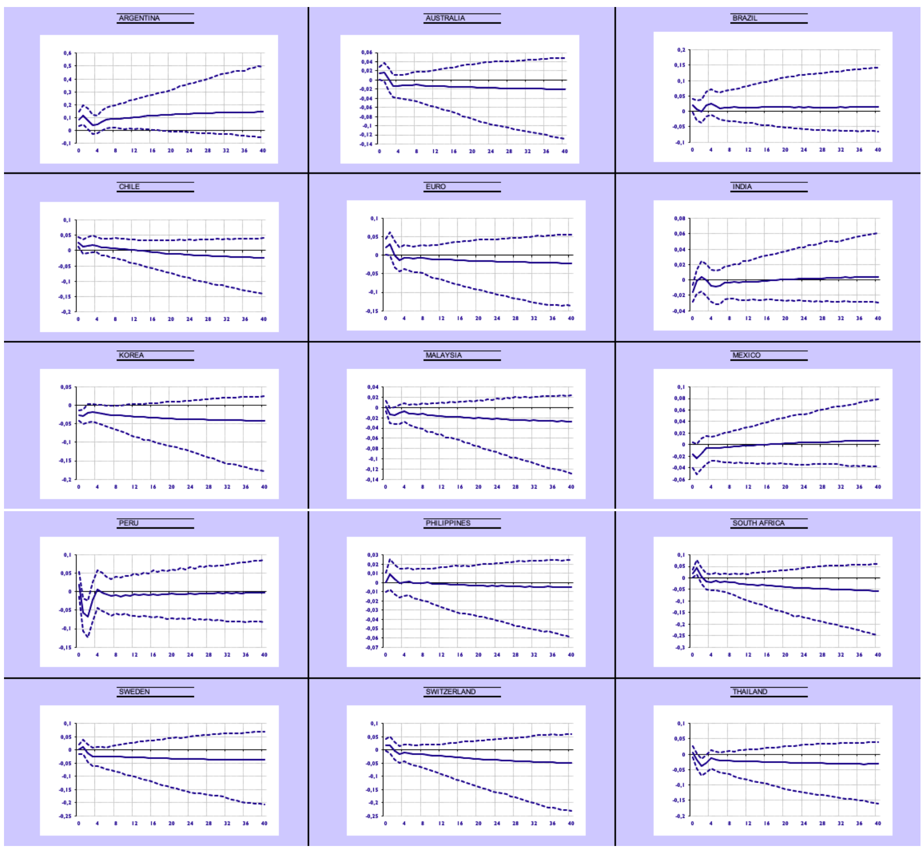

Figure 27: Response of exchange rates to the US shock - part 1

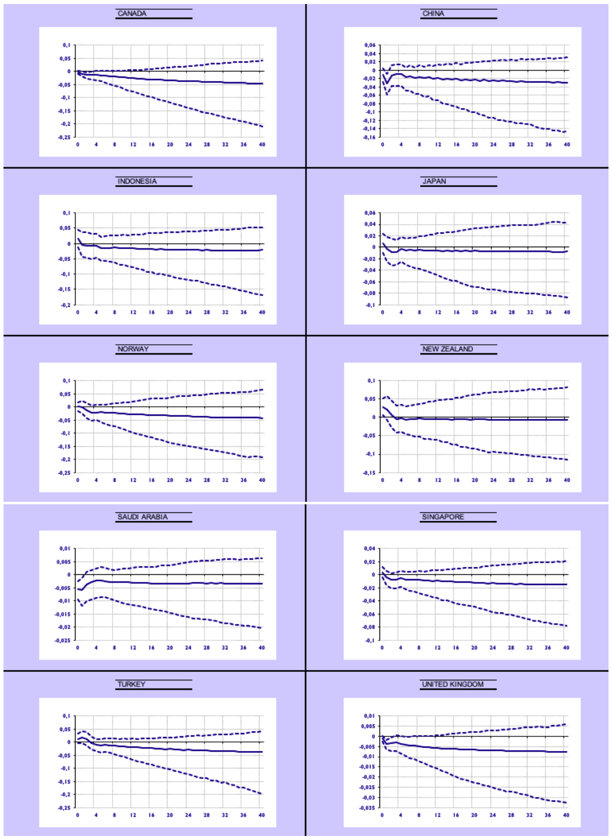

Figure 28: Response of exchange rates to the US shock - part Ĭ

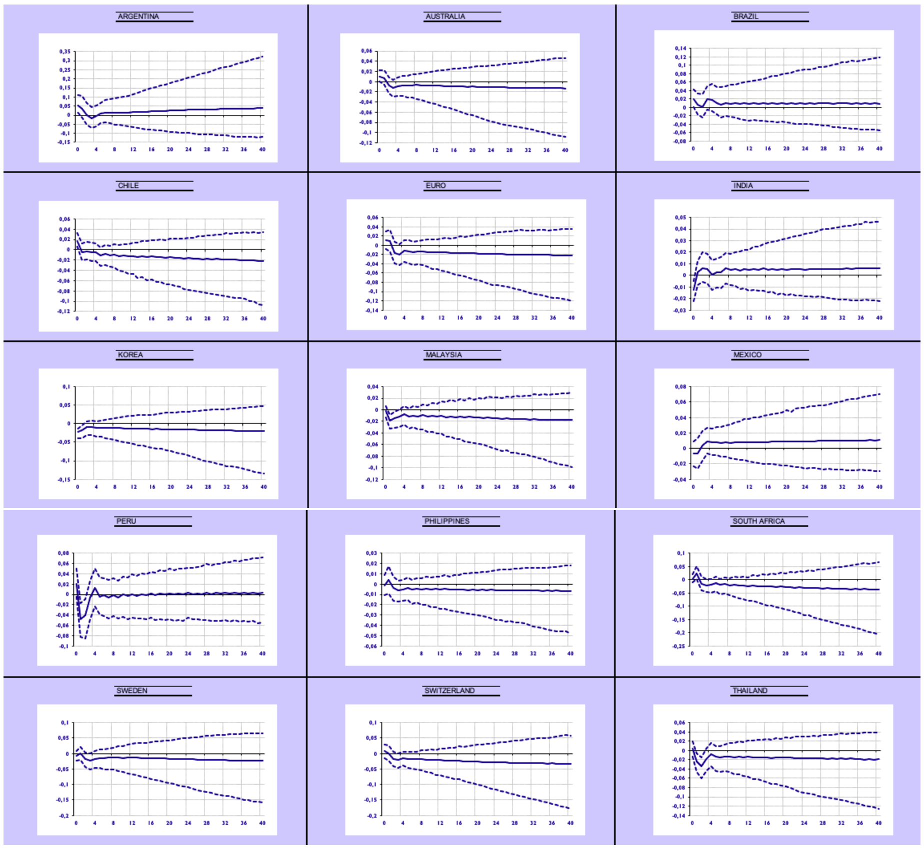

Figure 29: Response of exchange rates to the UK shock - part 1

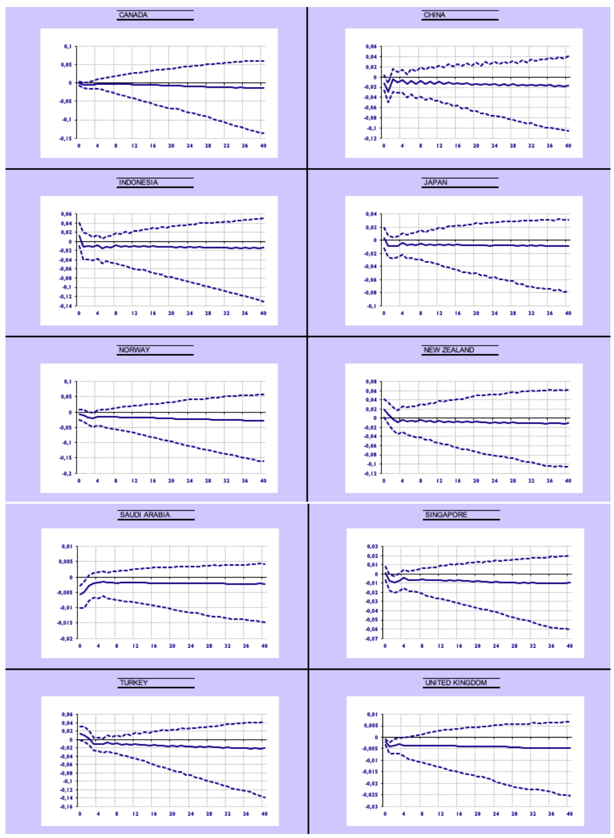

Figure 30: Response of exchange rates to the UK shock - part 2

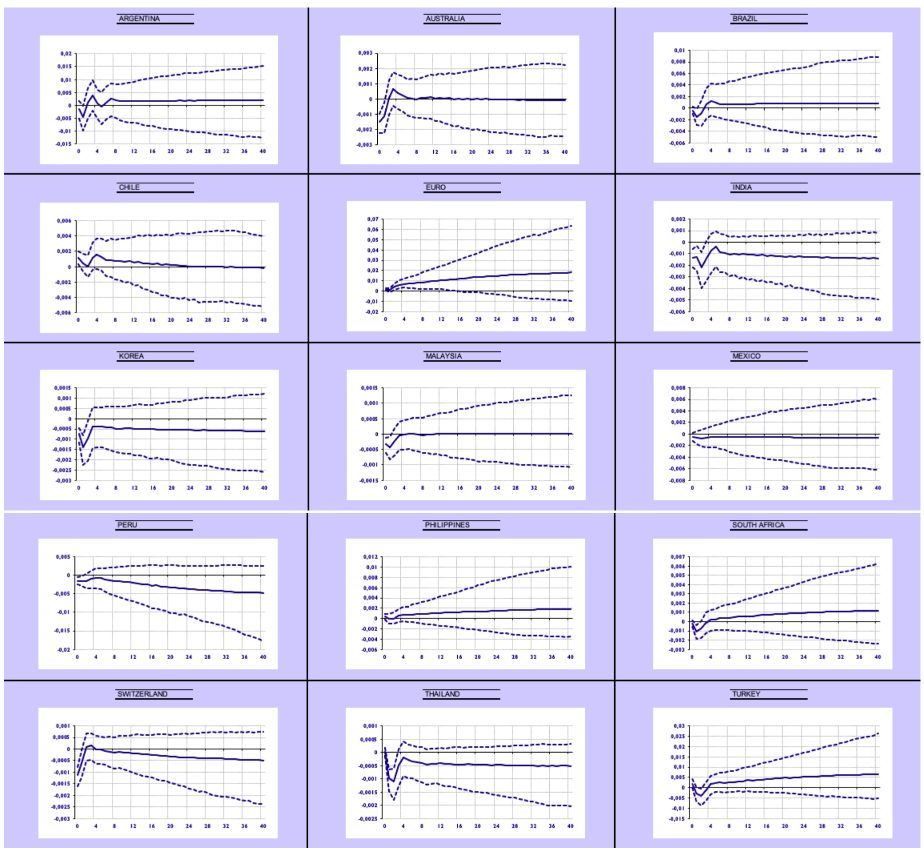

Figure 31: Response of short-term rates to the US shock - part 1

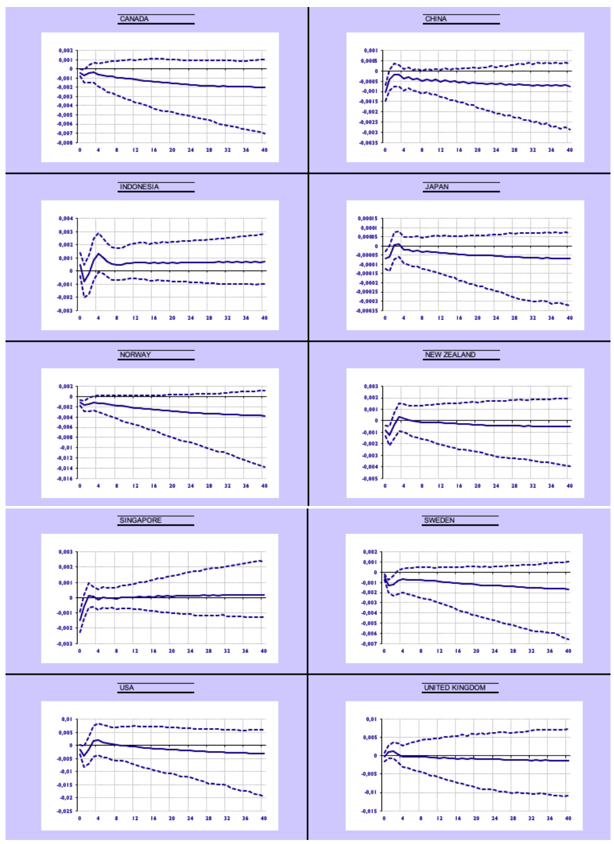

Figure 32: Response of short-term rates to the US shock - part 2

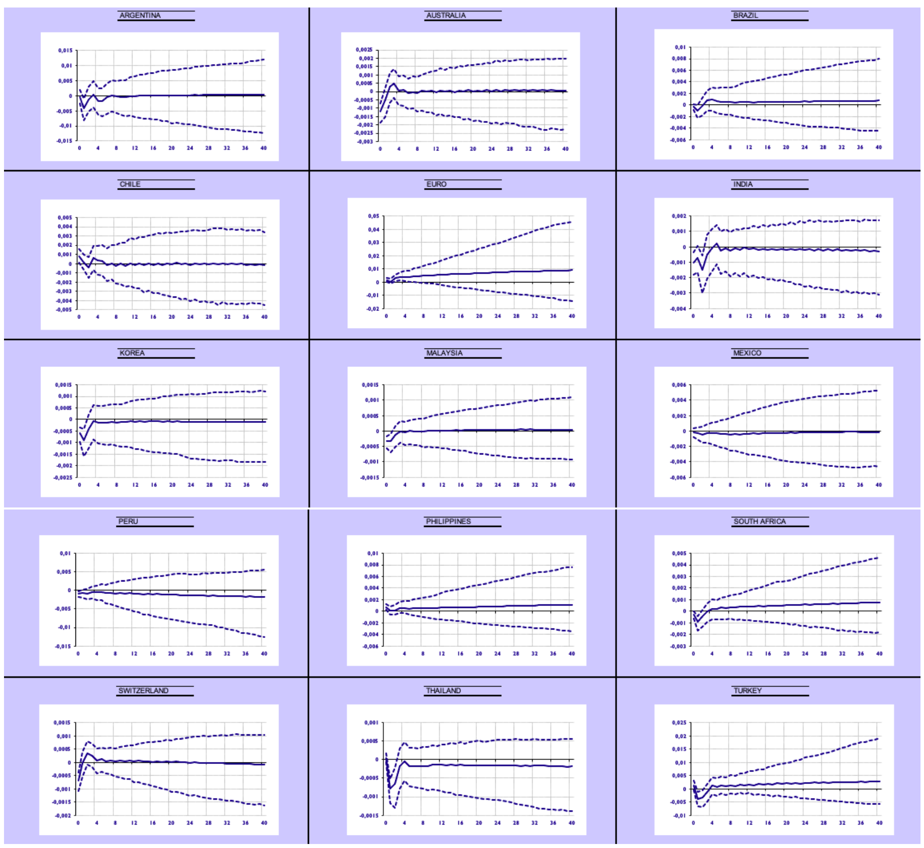

Figure 33: Response of short-term rates to the UK shock - part 1

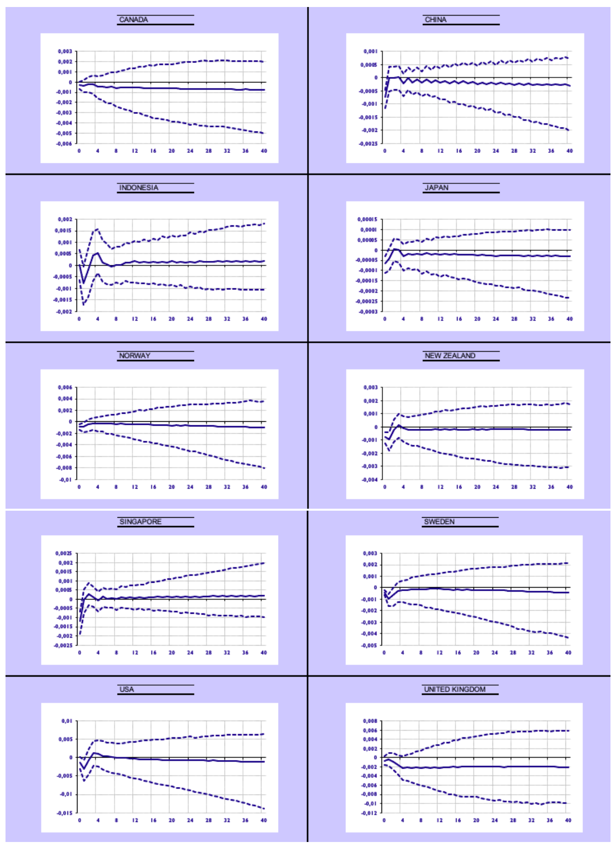

Figure 34: Response of short-term rates to the UK shock - part 2