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Global and Domestic Modeling of Macroeconomic Shocks: A GVAR Analysis of Ireland

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Non-Technical Summary

This paper examines the effects of large global shocks on the macroeconomy of Ireland and identifies the transmission channels through which such shocks propagate. In the post-crisis period, most countries have experienced a return to positive growth, fuelled in part by low interest rate policies and increased capital and trade flows. However, despite this global recovery, there remains considerable downside risk resulting from a number of sources: oil price volatility remains high, with substantial price reductions since mid-2014; China has experienced a growth slowdown, with further output declines expected as the Chinese economy moves away from investment towards consumption; US monetary policy has turned towards tightening, as inflation pressures become more prevalent; and the UK referendum on EU membership has resulted in heightened global financial market uncertainty, with additional negative impacts on the UK's trading partners.

Given that global interest rates remain at or near the zero lower bound, while public debt overhang and persistent deficits remain a legacy of the crisis in a number of countries, there remains limited scope for either accommodative monetary or fiscal policy in the event of these downside risks. Concerns over the impact of the above global shocks motivate the focus of this paper; to analyse the macroeconomic responses to global economic shocks, from the perspective of Ireland and its main trading partners.

A greater understanding of how large global shocks affect the Irish economy is important from a policy perspective, as it not only identifies the shocks to which the Irish economy is most susceptible, but also identities the different transmission channels through which such exogenous shocks impact the Irish economy. Such an identification is important, as policy responses designed to mitigate the effects of a shock to a specific variable (e.g. output) should consider the secondary impacts that such responses could have on alternative variables (e.g. inflation, interest rates) and whether the policy response diminishes or exacerbates the effects of the original shock on these variables. Furthermore, determining the magnitude of the response of Irish macroeconomic variables to global shocks is important for determining the appropriate scale of the chosen policy response.

Controlling for domestic output, inflation, exchange rates, equity prices, short and long-run interest rates, plus global oil, material and metal prices, the objective of this paper is to determine the effects of large external shocks on the Irish economy in a global setting, based on the macroeconomic shocks that are considered by forecasters to possess the greatest degree of downside risk to the global economy. Using an IMF dataset of 25 countries from 1980 to 2016, we employ the global vector auto-regression (GVAR) model of Dees, di Mauro, Pesaran and Shin (2007) to identify exogenous shocks to global output, oil prices, UK output and exchange rates, US interest rates, and Chinese output.

The analysis suggests that the Irish economy is relatively more exposed to: US interest rate tightening; UK exchange rate depreciations; and UK output declines, and relatively less exposed to a rise in global oil prices. Overall, the results of the empirical analysis show that exogenous shocks to external macroeconomic factors have sizable and significant effects on the domestic Irish economy, unsurprising given our role as a small open economy with a high degree of trade and financial account openness.

Global and Domestic Modelling of Macroeconomic Shocks: A GVAR Analysis of Ireland*

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Abstract

This paper studies the effects of external macroeconomic shocks on Ireland. Using a weighting scheme based on international trade linkages, we apply a global vector autoregressive model (GVAR) to investigate the degree of shock transmission between Ireland and a number of advanced countries / regions. Constructing a global model of 25 countries over the 1980q1-2016q1 sample period, we examine responses to five distinct shocks: a US interest rate hike; a decline in UK GDP; a depreciation of UK exchange rates; a reduction in Chinese output; and a global economic slowdown. Results suggest that Ireland is relatively more exposed to shocks to the UK economy, than either the euro area or the US, while it is relatively more insulated to movements in oil prices.

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1 Introduction

The decade before the Global Financial Crisis was characterized by a near global increase in trade openness, international financial integration, and business and financial cycle synchronisation. While advanced economies actively promoted the globalisation template for economic stability and growth, economic policy remained focused at the domestic level. Thus, the structural changes resulting from increased levels of economic and financial integration were unaccounted for in the development of policy responses to large macroeconomic shocks.

Critically, this increased level of cross-country interdependence has increased the degree to which most countries are exposed to external financial and economic shocks. As the initial growth period of globalisation coincided with a period of relatively low volatility in the global economy, there existed little evidence of these increased domestic exposures. However, even if such evidence had existed, it remains unlikely that such issues would have been identified before the global financial crisis, given that we only now appreciate the degree to which financial and economic vulnerabilities developed in the pre-crisis periods. Similarly, the abilities of domestic authorities and supra-national networks to manage global shocks in an environment of increased trade and financial integration were untested during this period.

While the initial periods of the financial crisis saw a large-scale capital retrenchment in most advanced countries, leading to a decline in financial integration, cross-border financial flows recovered post-2010, and have since returned to pre-crisis levels. Consequently, it remains important, when considering small open economies and the vulnerabilities to which they are exposed, that external and global shocks are fully considered. This is particularly true of Ireland, with highly asymmetric economic linkages, large net external positions, a financial infrastructure consistent with its classification as an offshore financial centre, and externally set monetary and exchange rate policy. Macroeconomic policy, macro-prudential policy and risk management necessitate taking account of the connections between the domestic Irish economy and global conditions, including economic conditions in other inter-connected economies, international financial markets and worldwide commodity prices.

Consequently, the aim of this paper is to identify a set of large economic shocks, with potentially global impacts, and estimate their effects on Ireland and its main trading partners. Ireland's integration into the global economy is characterized by a combination of export and import growth, and highly negative net external positions due to high net external liabilities. This growth in trade has principally involved Ireland's traditional trading partners: the UK, the US, and the core EU countries, but China has also established itself as one of Ireland's main import partners. We therefore apply a global VAR model, incorporating quarterly data from 25 countries, to analyse the degree of linkages and shock transmission between Ireland and the US, the UK, the euro area (consisting of the core EA member states) and China. In addition, there are a number of global factors that can be economically influential. Therefore, we also consider the effects of shocks to global output growth and oil prices. To the best of our knowledge, this is the first paper to focus on the response of Irish macroeconomic variables to exogenous, external shocks using a global VAR approach.

An additional feature of our analysis is that it not only allows for a direct comparison of the economic integration between Ireland and the euro area, but also provides a measure of their degree of business cycle synchronisation. Frankel and Rose (1998) highlights that countries with a considerable degree of trade linkages possess similar business cycles, with trade linkages fostering the transmission of aggregate shocks across countries: a positive export shock in a given country or region may increase demand for import goods from the trading-partner countries. Similarly, Forbes and Chinn suggests that direct trade between countries is one of the main determinants of cross-country linkages, while Burstein et al. (2008) develop a model that shows a positive link between trade and business cycle synchronization.

The rest of the paper is organized as follows. Section 2 provides a brief review of the literature on modelling global shocks in a macroeconomic VAR setting. Section 3 outlines the theoretical structure to the GVAR approach, while Section 4 presents the data to be used in the analysis. Section 5 outlines some static analysis of the VARX* models, while Section 6 discusses the structure to the dynamic analysis of the specified GVAR model and presents the generalised impulse response functions for the country-specific and global shocks. Section 7 concludes the paper.

2 Related Literature

Since its initial development by Pesaran, Schuermann and Smith (2004), the Global VAR (GVAR) approach has provided a robust method for analysing complex, high-dimensional systems in a closed-form model. While they were not the first to develop a technique to analyse the world through a large global macroeconomic framework, their ability to neatly deal with the curse of dimensionality advantaged them over alternative model structures (including the Fair model, NIGEM, the MIT model and the Computable General Equilibrium model).

Dees, di Mauro, Pesaran and Shin (2007) was the first paper to apply GVAR techniques to conventional macroeconomic analysis, updating the work of Pesaran, Schuermann, and Weiner (2004). Expanding the country sample from 26 to 33, the aim of the paper is to identify the transmission channels of specific economic and financial shocks, with a focus on the responses of the euro area region. Additionally, the framework of the original paper is enhanced to include a sieve bootstrap procedure for model simulation, while generalized impulse response functions are incorporated into the dynamic analysis. Results suggest that financial shocks propagate faster, and amplify at a greater rate, than macro shocks. Specifically, the paper finds US equity and oil prices to impact strongly on euro area output, inflation and interest rates, while a shock to US interest rates does not significantly affect any of the euro area variables.

To identify the role of relative price shocks and structural factors in global inflation rates, Anderton, Galesi, Lombardi and di Mauro (2010) develops a GVAR model of the world economy. Controlling for core inflation, headline inflation, industrial production, short-term interest rates and the nominal effective exchange rate within each of the 33 countries in the model, the paper simulates global food and oil price shocks and estimates responses over a two-year horizon period. Focusing on the US and the euro area, oil price shocks are found to have significant short-term impacts on headline inflations rates, with the initial magnitude of the US shock response twice that of the euro area response. Effects on core inflation rates are not found to be statistically significant. Additionally, industrial production is also found to decline significantly in the US and the euro area, following an oil price shock, with the magnitude of the response again identified as being larger in the US than in the euro area.

Dees, Pesaran, Smith and Smith (2010) estimate New Keynesian Phillips Curves, for eight developed economies, from a global perspective. Rather than employing a standard GMM-based identification strategy that requires using statistical criteria to identify instruments from lagged observations, the paper uses the GVAR framework to estimate the NKPCs for 26 countries, with the model's global factors acting as valid instruments to alleviate the issue of weak instruments. Similarly, the GVAR long-run horizon forecasts are used to calculate the long-run steady states, avoiding the need to use a statistical process (e.g. the Hodrock-Prescott filter) to calculate steady states as the long-run trend levels of variables. As a further benefit over traditional modelling approaches, the GVAR allows for a straightforward way for the foreign output gap and inflation to enter the estimation of the NKPC.

Cashin, Mohaddes, Raissi and Raissi (2014) uses the GVAR framework to identify both supply and demand shocks to oil prices, for a sample of 38 countries. Incorporating sign restrictions into the GVAR model, they find that the magnitudes and transition paths of supply-driven oil price shocks are significantly different from those of demand-side oil price shocks. The paper incorporates both real and financial economic variables to trace the country-level effects of oil shocks, using the cross-sectional dimension of the model to identify global shocks. Results suggest that impulse responses to output and inflation are conditional on whether the country is an oil importer or exporter: importers experience a decline in output following a supply side-lead oil price shock, while output rises in oil exporting countries. In contrast, a demand side-lead increase in the price of oil increases the long-run rate of inflation, with short run increases in output, for almost all countries in the sample.

3 Estimation Strategy

In its simplest form, the GVAR model can be considered as a two-stage process. In the first stage, conventional VAR models that are augmented by weakly $I(1)$ variables, including domestic and cross-sectional averages of foreign variables, are specified and estimated for each country/region in the sample. Using this augmented VAR (or VARX*) specification, each country is modelled as a small open economy, in which domestic variables are influenced by both country-specific foreign variables and global factors. In the second stage, the individual-country VARX* models are stacked into a single system of equations, connected through a matrix of predetermined cross-country linkages, and solved as a single system.

3.1 Country-specific VARX* Models

Consider a set of $N+1$ countries, representing a subset of the global economy, indexed by $i = 0, 1, \ldots N$, where 0 represents a reference country. Let each country, i, be modelled as a system:

$$\begin{aligned}\mathbf{x}_{i,t} = \boldsymbol{\alpha}_{i0} + \boldsymbol{\alpha}_{i1}t + \boldsymbol{\Phi}_{i1}\mathbf{x}_{i,t-1} + \cdots + \boldsymbol{\Phi}_{ip_i}\mathbf{x}_{i,t-p_i} + \\ \boldsymbol{\Lambda}_{i0}\mathbf{x}^*_{i,t} + \boldsymbol{\Lambda}_{i1}\mathbf{x}^*_{i,t-1} + \cdots + \boldsymbol{\Lambda}_{iq_i}\mathbf{x}^*_{i,t-1} + \\ \boldsymbol{\Gamma}_{i0}\mathbf{g}_t + \boldsymbol{\Gamma}_{i1}\mathbf{g}_{t-1} + \cdots + \boldsymbol{\Gamma}_{iq_i}\mathbf{g}_{t-q_i} + \boldsymbol{\varepsilon}_{i,t}\end{aligned} \tag{1}$$

where $t = 0, 1, 2, \ldots, T$; $\mathbf{x}_{i,t}$ is a $(k_i \times 1)$ vector of domestic variables specific to country i at time t ; $\mathbf{x}^*_{i,t}$ is a $(k^*_i \times 1)$ vector of foreign variables specific to country i at time t ; $\boldsymbol{\alpha}_{i0}$ is the $(k_i \times 1)$ vector of fixed intercept coefficients ; $\boldsymbol{\alpha}_{i1}$ is the $(k_i \times 1)$ vector of deterministic time trends ; $\boldsymbol{\Phi}_{i.}$ is a $(k_i \times k_i)$ matrix of lagged domestic variable coefficients ; $\boldsymbol{\Lambda}_{i.}$ is $(k_i \times k^*_i)$ matrix of foreign-specific variables; $\boldsymbol{\Gamma}_{i.}$ is the $(k_i \times k^\circ_i)$ matrix of fixed coefficients attached to the $(k^\circ_i \times 1)$ vector of common global variables, $\mathbf{g}_t$, which is assumed to be weakly exogenous to the global economy; and $\boldsymbol{\varepsilon}_{i,t}$ is a $(k_i \times 1)$ vector of country-specific idiosyncratic shocks, where $\boldsymbol{\varepsilon}_{i,t} \sim i.i.d(\mathbf{0}, \boldsymbol{\Sigma}_{ii})$.

Modelling the system using a GVAR allows for a non-zero contemporaneous shock dependence structure across countries, through the set of cross-country covariances, so that

$$\boldsymbol{\Sigma}_{ij} = Cov(\boldsymbol{\varepsilon}_{i,t}, \boldsymbol{\varepsilon}_{j,t}) = E(\boldsymbol{\varepsilon}_{i,t_i}\boldsymbol{\varepsilon}'_{j,t_j}) \;\; \forall\, i \neq j \text{ and } t_i, t_j \in t \tag{2}$$

In calculating the matrix of individual country-specific foreign variables, $\mathbf{x}^*_{it}$, each variable is constructed using a set of fixed weights. The weights are calculated using cross-country weighted averages of the corresponding variables given by the weighting share, such that w_{ij} is the weight share of country j in the total weighting of country i, measured in a common unit. Using this methodology, it must be the case that

$$w_{ii} = 0, \ \ \forall\, i = 0, 1, 2, \ldots, N \tag{3}$$

and

$$\sum_{j=0}^{N} w_{ij} = 1, \ \ \forall\, i, j = 0, 1, 2, \ldots, N \tag{4}$$

Under this structure, we can define the set of foreign specific variables for country i, $\mathbf{x}^*_{i,t}$ as

$$\mathbf{x}^*_{i,t} = \sum_{j=0}^{N} w_{ij} \mathbf{x}_{j,t} \tag{5}$$

where w_{ij} are the fixed weights attached to the foreign variables.

For the majority of the countries included in the GVAR, both the foreign variables, $x^*_{i,t}$, and the global variables, $\mathbf{g}_t$, are treated as being weakly exogenous, allowing for country/region-specific models to be estimated consistently. For all countries in which the foreign variables are treated as weakly exogenous, their representation is equivalent to being a SOE, in that, relative to their trading partners, their policies and domestic economic shocks have no first-order effects on values of the global variables.

While foreign variables are weakly exogenous in most countries, we allow country-specific, domestic shocks to be weakly correlated with shocks in other economies in the model, through the interaction of domestic and foreign variables. Shocks are assumed to be serially uncorrelated and weakly dependent across the cross-sectional dimension, such that for all time periods, t , in the sample

$$\boldsymbol{\varepsilon}^*_{i,t} = \sum_{j=0}^{N} w_{ij} \boldsymbol{\varepsilon}_{j,t} \xrightarrow{q.m} 0 \tag{6}$$

while the idiosyncratic shocks, $\varepsilon_{i,t}$, are correlated across countries/regions, so that

$$E(\boldsymbol{\varepsilon}_{i,t_i} \boldsymbol{\varepsilon}'_{j,t_j}) = \begin{cases} \boldsymbol{\Sigma}_{ij} & \forall t_i = t_j \\ 0 & \forall t_i \neq t_j \end{cases} \tag{7}$$

By imposing the above structures on the system, the GVAR model allows for interactions among the set of countries/regions in the system, through three distinct but related transmission channels

1. The direct dependence of the domestic variables, $\mathbf{x}_{i,t}$, on the set of foreign variables, $\mathbf{x}^*_{i,t}$, and their lagged values.
2. The dependence of the domestic variables on the set of exogenous global variables, $\mathbf{g}_t$, and their lagged values .
3. The contemporaneous dependence of shocks in country i on shocks in country j, estimated via the non-zero matrix of cross-country covariances, $\mathbf{\Sigma}_{ij}$.

The exogeneity requirement of the foreign-specific and global variables are a key assumption of the GVAR, allowing for a complete, closed system that resolves the standard curse of dimensionality and allows for scenario analysis. Whether this assumption, while consistent with the international macroeconomic literature that considers "world" variables to be exogenously given, holds empirically is entirely dependent on the size of the countries/regions in the global model and the degree of cross-country heterogeneity present in the country-specific idiosyncratic shocks, $\varepsilon_{i,t}$, as captured by the covariance matrix $\mathbf{\Sigma}_{ij}$. Evidence to support the weak exogeneity of these variables is presented in the Appendix.

3.2 Aggregation to the Global VAR Model

With the individual VARX* models specified, as per equation (1), we can now solve for the global system, through stacking the individual models together. As in each country-specific VARX* model, there is contemporaneous dependence between the vector of domestic variables, $\mathbf{x}_{i,t}$, and the vector of foreign and global variables, $\mathbf{x}^*_{i,t}$, the full set of models needs to be solved simultaneously, for all domestic variables in $\mathbf{x}_{i,t}$, and $\forall\ i = 0, 1, 2, \ldots, N$.

Considering the representative SOE, for whom global variables are not endogenously determined, equation (1) becomes

$$\begin{aligned} \mathbf{x}_{i,t} = \boldsymbol{\alpha}_{i0} + \boldsymbol{\alpha}_{i1}t + \mathbf{\Phi}_{i1}\mathbf{x}_{i,t-1} + \cdots + \mathbf{\Phi}_{ip_i}\mathbf{x}_{i,t-p_i} + \\ \mathbf{\Lambda}_{i0}\mathbf{x}^*_{i,t} + \mathbf{\Lambda}_{i1}\mathbf{x}^*_{i,t-1} + \cdots + \mathbf{\Lambda}_{iq_i}\mathbf{x}^*_{i,t-1} + \boldsymbol{\varepsilon}_{i,t} \end{aligned} \tag{8}$$

where the global variables are now included in the vector of foreign variables, $\mathbf{x}^*_{i,t}$. To construct the GVAR model from the set of these country-specific models, we define the stacked $(k_i + k^*_i) \times 1$ vector of domestic and foreign variables for each country, as

$$\mathbf{z}_{i,t} = \begin{pmatrix} \mathbf{x}_{i,t} \\ \mathbf{x}^*_{i,t} \end{pmatrix} \tag{9}$$

Equation (8) can then be re-written as

$$\mathbf{A}_{i0}\mathbf{z}_{i,t} = \boldsymbol{\alpha}_{i0} + \boldsymbol{\alpha}_{i1}t + \mathbf{A}_{i1}\mathbf{z}_{i,t-1} + \cdots + \mathbf{A}_{ip_i}\mathbf{z}_{i,t-p_i} + \boldsymbol{\varepsilon}_{i,t} \tag{10}$$

where

$$\mathbf{A}_{i0} = \begin{pmatrix}\mathbf{I}_{ki} & -\boldsymbol{\Lambda}_{i0}\end{pmatrix} \quad and \quad \mathbf{A}_{ij} = \begin{pmatrix}\boldsymbol{\Phi}_{ij} & \boldsymbol{\Lambda}_{ij}\end{pmatrix} \quad \forall \quad j = 1, 2, ...p_i \tag{11}$$

To stack the models, we can collect the country specific variables into a $(k \times 1)$ global vector of variables, $\mathbf{x}_t = \begin{pmatrix}\mathbf{x}'_{0t} & \mathbf{x}'_{1t} & \cdots & \mathbf{x}'_{Nt}\end{pmatrix}'$ where k is the total number of endogenous variables in the global model.

In addition, we need to define a linking matrix, $\mathbf{W}_i$, a $((k_i + k_i^*) \times k)$ matrix whose elements are the weights capturing bilateral exposures between the countries/regions that constitute the system. This link matrix specifies the interconnections between pairs of countries, allowing for each of the country-specific VARX* models to be represented in terms of the global variables vector, as

$$\mathbf{z}_{i,t} = \mathbf{W}_i\mathbf{x}_t \quad \forall i = 0, 1, 2, \cdots, N. \tag{12}$$

Combining equations (10) and (12) results in the country-specific equation being represented as

$$\mathbf{A}_{i0}\mathbf{W}_i\mathbf{x}_t = \boldsymbol{\alpha}_{i0} + \boldsymbol{\alpha}_{i1}t + \mathbf{A}_{i1}\mathbf{W}_i\mathbf{x}_{t-1} + \cdots + \mathbf{A}_{ip_i}\mathbf{W}_i\mathbf{x}_{t-p_i} + \boldsymbol{\varepsilon}_{i,t} \tag{13}$$

where $\mathbf{A}_{i0}\mathbf{W}_i$ and $\mathbf{A}_{ij}\mathbf{W}_i$ are all $(k_i \times k)$ dimensional matrices. Stacking these equations into a single equation for the system yields

$$\mathbf{G}\mathbf{x}_t = \boldsymbol{\alpha}_0 + \boldsymbol{\alpha}_1 t + \mathbf{H}_1\mathbf{x}_{t-1} + \cdots + \mathbf{H}_p\mathbf{x}_{t-p} + \boldsymbol{\varepsilon}_t \tag{14}$$

where

$$\mathbf{G}_0 = \begin{pmatrix}\mathbf{A}_{00}\mathbf{W}_0 \\ \mathbf{A}_{10}\mathbf{W}_1 \\ \vdots \\ \mathbf{A}_{N0}\mathbf{W}_N\end{pmatrix} \mathbf{G}_j = \begin{pmatrix}\mathbf{A}_{0j}\mathbf{W}_0 \\ \mathbf{A}_{1j}\mathbf{W}_1 \\ \vdots \\ \mathbf{A}_{Nj}\mathbf{W}_N\end{pmatrix} \boldsymbol{\alpha}_0 = \begin{pmatrix}\boldsymbol{\alpha}_{00} \\ \boldsymbol{\alpha}_{10} \\ \vdots \\ \boldsymbol{\alpha}_{N0}\end{pmatrix} \boldsymbol{\alpha}_1 = \begin{pmatrix}\boldsymbol{\alpha}_{01} \\ \boldsymbol{\alpha}_{11} \\ \vdots \\ \boldsymbol{\alpha}_{N1}\end{pmatrix} \boldsymbol{\varepsilon}_t = \begin{pmatrix}\boldsymbol{\varepsilon}_{0,t} \\ \boldsymbol{\varepsilon}_{1,t} \\ \vdots \\ \boldsymbol{\varepsilon}_{N,t}\end{pmatrix} \tag{15}$$

The $\mathbf{G}_0$ matrix is a $k \times k$ dimensional matrix. Subject to fulfilling rank conditions, we can pre-multiply the system of equations by $\mathbf{G}_0^{-1}$ to obtain the autoregressive representation of the $\mathrm{GVAR}(p)$ model

$$\mathbf{x}_t = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1 t + \mathbf{F}_1\mathbf{x}_{t-1} + \cdots + \mathbf{F}_p\mathbf{x}_{t-p} + \boldsymbol{\epsilon}_t \tag{16}$$

where $\boldsymbol{\beta}_0 = \mathbf{G}_0^{-1}\alpha_0$, $\boldsymbol{\beta}_1 = \mathbf{G}_0^{-1}\alpha_1$, $\mathbf{F}_j = \mathbf{G}_0^{-1}\mathbf{B}_j$ and $\boldsymbol{\epsilon}_t = \mathbf{G}_0^{-1}\boldsymbol{\varepsilon}_t$. As the country-specific bilateral weights are subject to the adding-up restriction, $k = \sum_{i=0}^{N} k_i = 1$, the link matrices, $\mathbf{W}_i$, must be non-singular.

In the form shown in equation (16), the $GVAR(p)$ model may be solved recursively, allowing for the development of forecasts, impulse response function and forecast error variance decompositions, as per standard $\mathrm{VAR}(p)$ frameworks. This is accomplished using the $\boldsymbol{\epsilon}_t$ vector, a $(k \times 1)$ vector of reduced-form shocks that are linear functions of the country-specific shocks, $\boldsymbol{\varepsilon}_t$, with

$$var(\boldsymbol{\epsilon}_t) = \Sigma_\epsilon = \mathbf{K}^{-1}\Sigma_\varepsilon\mathbf{K}^{-1\prime} \tag{17}$$

No restrictions are placed on the covariance matrix, Σ_ε .

4 Data and model specification

In this section, we present the data used in our empirical application of the GVAR model, discuss the rationale for the choice of weighting matrices employed in the analysis, and highlight the choices in parameter selection at each stage of the procedure.

4.1 Sample Selection and Regional Aggregation

To estimate our GVAR model, we make two specific choices regarding the sample of data on which the model is estimated. With respect to the cross sectional elements of our data, we select 25 advanced and emerging market economies, which together account for the majority of movements in the global economy. Averaging over the sample, these economies account for over 88% of global gross domestic product, over 66% of global trade in goods and services, and the majority of the exposures of the globally active banks in the G-7 countries. As per Smith and Galesi (2014), we only aggregate countries across a single specific region; the euro area. Table 1 presents the set of countries and regions in the model.

Our choice of countries is in part conditioned on data availability. While the GVAR model imposes limited restrictions on correlation structures or country interdependences, a requirement of the model is that there are no gaps in the data series used to construct the system. Thus, we need data for which there is a complete time series available for the entire sample period under observation; otherwise, the series is excluded from the model's estimations. With this in mind, we exclude countries that i). have missing observations for more than two data series in the sample, and ii). provide a total contribution to global GDP of less than 3 per cent. While these criteria reduce our sample from the 33 countries considered by Chudik and Smith (2013), the countries dropped from our sample are those whose data are subject to considerable revisions. Thus, we are confident that the loss of power to our model from the reduced sample-size is compensated for by the increased accuracy of the estimated domestic and cross-country relationships.

Our choice of regional aggregation attempts to combine historical accuracy with current representativeness. Given that our sample extends back to 1980, over half of our data predate the creation of the euro area. Consequently, it does not seem appropriate to model all countries currently in the euro area as influencing movements in euro area variables over the entire sample period. Instead, following the logic of Chudik and Smith (2013) and Dées, di Mauro, Pesaran and Shin (2007), we model the euro area as consisting of the largest 8 of the original 11 member states. In doing so, we strike a balance between a cluster that is small enough to represent the core drivers of the euro-region economy prior to the EMU, but large enough to be considered as the set of countries whose economic characteristics drive post-euro ECB policy decisions.

4.2 Variable Selection and Transformation

As with all large macroeconomic models that require a system of equations, the choice of variables employed in the GVAR is non-trivial, due to the proliferation of parameters as the dimension of the model grows. Thus, we aim to strike a balance between imposing sufficient restrictions on the model so that the parameters can be consistently estimated, while at the same time allowing for a general pattern of interdependencies between the individual variables, without imposing excessive restrictions on the domestic and foreign lag selection criteria. [1]

We select six variables that form the basis of the domestic and foreign components of the country-specific VARX* models. The real economy component of our models consists of gross domestic product (gdp) and consumer price index-based inflation (cpi). Policy variables include the short-term interest rate (irs) and the real dollar exchange rate (rer), while an index of equity prices ($eqty$) is included to allow for macro-financial linkages. Finally, we include a measure of long-term interest rates on government bonds (irl).

There are a number of reasons behind, and benefits to, the selection of this set of variables. By including both short-term interest rates and exchange rates, it is possible to either test or impose long-run relationships on our model, including purchas-

[1] In our final model specification, we use six domestic variables, a maximum of five cross-sectional foreign variables, and three dominant unit variables. Specifying a maximum of three domestic variable lags, two foreign variable lags, and two dominant unit variable lags, leads to a maximum of 42 unobserved parameters to be estimated in the country-specific VARX* models. Given that the time-dimension our data covers 145 periods, we believe that there are sufficient degrees of freedom to instil confidence in the output of the GVAR model.

ing power parity (PPP) and uncovered interest rate parity. Similarly, by incorporating measures of equity markets, we can examine the role of real exchange rates in the transmission of financial shocks to the real economy. Additionally, by including long-term interest rates, we not only control for non-standard policy responses due to the zero lower bound on short-run interest rates in the aftermath of the Global Financial Crisis, but we can also identify the degree of policy coordination through co-movement between long-term interest rates between trade and financial partners, while allowing for the effects of changes in risk premia on the model.

Finally, we employ three global variables in the model. As per Smith and Galesi (2014), we incorporate international oil prices ($poil$), metals prices ($pmet$) and materials prices ($pmat$). These variables will be constructed as being weakly exogenous to the country-level VARX* models, with feedback only occurring through changes in a specific subset of the foreign variables in the model.

With our set of domestic, foreign and global variables selected, we must now transform the data. In line with Dées, di Mauro, Pesaran and Shin (2007), we apply the following transformations

$$\begin{aligned} gdp_{i,t} &= ln(\tfrac{Y_{i,t}}{CPI_{i,t}}), \qquad cpi_{i,t} = ln(\tfrac{CPI_{i,t}}{CPI_{i,t-1}}), \qquad irs_{i,t} = 0.25 \times ln(1 + \tfrac{R^s_{i,t}}{100}) \\ eqty_{i,t} &= ln(\tfrac{EQ_{i,t}}{CPI_{i,t}}) \qquad rer_{i,t} = ln(\tfrac{ER_{i,t}}{CPI_{i,t}}) \qquad irl_{i,t} = 0.25 \times ln(1 + \tfrac{R^l_{i,t}}{100}) \end{aligned} \tag{18}$$

where $Y_{i,t}$ is nominal Gross Domestic Product, $CPI_{i,t}$ is the consumer price index, $EQ_{i,t}$ is the nominal value of the domestic equity price index, $ER_{i,t}$ is the dollar exchange rate, $R^s_{i,t}$ is the short-term interest rate and $R^l_{i,t}$ is the long-term interest rate.

Given data restrictions, we do not impose the requirement that all country-specific VARX* models contain the same set of domestic variables.

4.3 Weighting Structures

Given the set of domestic variables $(gdp_{i,t},\ cpi_{i,t},\ eqty_{i,t},\ rer_{i,t},\ irs_{i,t},\ irl_{i,t})$ defined in the previous section, we next construct an equivalent vector of country-specific foreign variables $(gdp^*_{i,t},\ cpi^*_{i,t},\ eqty^*_{i,t},\ rer^*_{i,t},\ irs^*_{i,t},\ irl^*_{i,t})$ using alternative weighting structures. As the construction of the foreign variables is dependent on the weighting matrix, $\mathbf{W}_i$, a key assumption of the GVAR model and its results is that $\mathbf{W}_i$ accurately captures the real-world economic linkages among countries.

From the previous literature, bilateral trade data are most commonly used in developing the GVAR linkage matrix. The justification for using trade data to link countries together is relatively intuitive. Baxter and Kouparitsas (2004) identify bilateral trade connections as being the most important source of cross-country business cycle linkages. Similarly, Auerbach and Gorodnichenko (2012) identify cross-country spillovers to domestic output resulting from foreign fiscal shocks, propagating through conventional trade channels.

Consequently, our weighting matrices are derived using fixed trade weights, based on the average trade flows over the $2012 - 2014$ period. Additionally, to construct the euro area region VARX* model, we use cross-section weighted averages of the set of domestic variables for Austria, Belgium, France, Finland, Germany, Italy, Netherlands and Spain. The weights that are used to construct this vector of variables are based on average PPP GDP figures for each country, using data from the $2012 - 2014$ period.

5 Static Empirical Analysis

Having confirmed that there is sufficient statistical evidence to suggest that the underlying assumptions of the model are consistent with the data, we now turn our attention to examining the static relationships that are estimated by the GVAR model. The dynamic analysis is underpinned by the both the relationship between domestic and foreign variables, and the cross-sectional "weak correlation" of idiosyncratic shocks from the VARX* models. Thus, it is important to identify whether such characteristics exist in the data, as they provide indications as to the mechanics of the GVAR, and the level of plausibility with respect to underlying macroeconomic interconnections.

5.1 Effects of Foreign Variables on Domestic Equivalents

To examine the strength of the interlinkages between countries, this section discusses the contemporaneous impact effects of changes to the set of foreign variables on the equivalent set of domestic variables. Within the GVAR framework, the country-specific VARX* models provide an estimate of the contemporaneous effect of variable x_i^* on the domestic variable x_i, for all variables included in the system. This parameter estimate can be interpreted as being the impact elasticity between foreign and domestic variables. These estimates provide a quantification of the model's identification of international linkages between specific countries and the rest of the system; the larger the parameter estimates, the greater the elasticity between domestic and foreign variables, the stronger the implied co-movement between both variables.

Table 2 presents the parameter estimates and standard errors for these elasticities. Standard errors are calculated using the Newey-West variance estimator, which is a heteroscedasticity-consistent estimator that allows for a small-sample correction. Overall, there is a strong degree of inter-connectivity found in the data, with almost 75% of coefficients found to be significant. Inflation and equity prices are found to have the strongest domestic-foreign linkages, both in terms of the number of significant relationships, and the high, positive values attached to the elasticities. Across the sample, five countries/regions are identified as having significant domestic-foreign relationships across all five variables, including the euro area, Canada and Switzerland.

Focusing on Ireland, elasticity values reflect the country's nature as a small open economy, with elasticity estimates above the sample average for all variables with the exception of the equity price series. In particular, the short and long-term interest rate series are identified as being the most elastic of any of the advanced economies in the sample, with respect to foreign interest rates. Furthermore, domestic-foreign relationships are found to be significant for four of the five variables: inflation; equity prices; short-term interest rates; and long-term interest rates.

5.2 Pairwise Cross-Section Correlations

The final modelling assumption inbuilt into the GVAR approach relates to the cross-sectional correlations of idiosyncratic shocks from the country-specific VARX* models. Inherent in the ability to stack the individual models to form the GVAR system is the requirement that the shocks modelled at the country level are cross-sectionally "weakly correlated", so that cov$(\mathbf{x}^*_{i,t}, u_{i,t}) \to 0$ as $N \to \infty$. Should this condition hold, this provides further evidence supporting the weak exogeneity of the foreign variables with respect to their domestic counterparts.

To examine the degree to which country-specific foreign variables have been effective in reducing the cross-section correlation of the variables in the GVAR model, Tables 3 and 4 present the average pair-wise cross-section correlation of the levels and first differences of the endogenous variables in x, in addition to residuals from their respective equations from the VECM* form of the country-specific models. By conditioning the country-specific models on the weakly exogenous foreign variables, residual interdependencies are stripped of correlates resulting from "common" global factors, leaving interdependencies that would more likely account for spillover effects due to economic policy and trade.

At the aggregate level, results suggest that cross-sectional correlations are considerable for the level of the endogenous variables. This holds across all variables, with average correlations ranging between 40.8% and 96.6%. Additionally, average cross section correlations fall going from levels to first differences, with correlations ranges falling to $10.6 - 48.8\%$. Within the set of endogenous variables, output levels show the highest degree of cross-sectional correlation $(91 - 98\%)$, but also the greatest impact resulting from first differencing $(4.3 - 30.5\%)$. In contrast, but unsurprisingly, cross-sectional equity price correlations are found to be the most resistant to differencing, with cross-sectional averages almost unchanged between levels and first differences. At the country level, the euro area, the United States and the United Kingdom show the highest average correlations across levels and first differences, while China and Argentina represent the countries with the lowest average cross-sectional correlations in both levels and differences. Overall, the tests show a considerable degree of evidence to support the assumption of cross-sectional correlations for the variables present in the GVAR, although the degree to which variables exhibit correlation structures depends on the country selected, the specific variables within a country, and whether differencing is applied to the variable.

Applying the same analysis to the residuals from the VARX* models, results suggest that the empirical approach applied to the data is successful in capturing cross-sectional correlations across variables and countries. At the aggregate level, the effects of the application of the VARX* model is most evidenced within the equity and long-run interest rate series. These variables showed the highest persistence in cross-sectional correlation following differencing, however, the resulting average correlation values for the residuals are estimated to be -1.82% and -1.24%, respectively. Similar results are obtained for output (0.57%), inflation (3.07%) and short-term interest rates (3.70%). The real exchange rate series remains the only endogenous variable that shows some remaining degree of cross-sectional correlation (18.8%), although this is much reduced from the level (78.4%) and differenced (33.5%) values. Similar results are obtained by Dees et al (2007), who also observe double-digit correlation estimates for their exchange rate series.

Overall, these results highlight the importance of accounting for cross-sectional correlations within a multi-country macroeconomic framework. By employing the country-specific foreign variables to account for global interdependencies, the shocks resulting from the empirical estimation are subsequently found to be (weakly) cross-sectionally independent. This provides additional evidence to the results in the Appendix, further suggesting that the shocks from the empirical model can be considered to be idiosyncratic.

6 Dynamic Empirical Analysis

Having tested the underlying assumptions and static outcomes of the GVAR model, we now turn our attention to estimating the dynamic responses of the model to identified economic shocks. Given the focus of the paper, we examine six key macroeconomic shocks from both an Irish perspective, but also from the viewpoint of the main Irish trading partners: the euro area; the US; and the UK. In each instance, we compare and contrast impulse responses from the unanticipated shock to output, inflation and interest rates.

Our choice of shocks again derives from our analysis being conducted from an Irish macroeconomic perspective. We examine the main external shocks that are currently considered to be a cause for concern for the Irish economy. Key amongst these are shocks to the United Kingdom's output and real exchange rates. Similarly, we also examine two shocks that are expected within the short to medium-term, namely an increase in the US short-term interest rate and a slowdown of Chinese output. Finally, we examine more global impacts, including an aggregate decline in global GDP and a shock increase in oil prices. It should be noted that these shocks are symmetric in their identification, so that the responses (for example) to the decline in global GDP are mirror images of responses to an aggregate increase in global GDP of the same magnitude, lending our analysis to a broader set policy questions than the scenarios presented here.

6.1 Generalized Impulse Response Functions

To examine dynamic properties of the GVAR model, and to determine the time path of the effect of our chosen shocks to the four economies discussed above, we employ the Generalized Impulse Response Functions of Koop et al. (1996) and Pesaran and Shin (1998). This variant of impulse response functions has been adopted in a number of macroeconomic fields, including financial and macroeconomic interconnectedness (Diebold and Yilmaz, 2009), international financial market analysis (Huang et al., 2008), exchange rate modelling (Cheung et. al, 2004; Boyd et al., 2001) and non-linear macroeconomic modelling (Lee and Pesaran, 2011). The popularity of the GVAR approach, versus more conventional orthogonalization techniques, lies in the invariance of the GIRF technique to the ordering of the variables. As such, it is not necessary to impose a structural ordering on either the set of variables in the VARX* models, or the set of countries in the GVAR model. Both of these requirements would be necessary to generate OIRFs via a Cholesky (or alternative) decomposition.

To see how the generalised impulse response functions are generated, consider the multi-country model presented in equation (14). Define the generalized impulse response (of one standard error in size) as

$$GIRF = (\mathbf{x}_t; \varepsilon_{i,l,t}, n) = E(\mathbf{x}_{t+n}|\varepsilon_{i,l,t} = \sqrt{\sigma_{ii,ll}}, I_{t-1}) - E(\mathbf{x}_{t+n}|, I_{t-1}) \tag{19}$$

where I_{t-1} is the information set available at time $t-1$, $\sigma_{ii,ll}$ is the diagonal element of the variance covariance matrix Σ_i corresponding to the l^{th} equation in the i^{th} country, and n is the forecast horizon period.

Assuming that residual terms from the VECM* equations have a multivariate normal distribution, it must be the case that the GIRFs corresponding to a shock of one standard error in size, at time t to the l^{th} equation in the GVAR from equation (14) on the j^{th} variable at time $t + n$ is given by the j^{th} element of

$$IRF = (\mathbf{x}_t; \varepsilon_{l,t}, n) = \frac{v_j' \mathbf{A}_n \mathbf{G}_0^{-1} \Sigma_\varepsilon v_l}{\sqrt{v_j' \Sigma_\varepsilon v_l}} \tag{20}$$

where $v_l = \begin{pmatrix} 0 & 0 & \dots & 0 & 1 & 0 & \dots & 0 \end{pmatrix}'$ is a selection vector with unity as the l^{th} element for a country-specific shock. For a regional shock to a variable, i.e. interest rates, the v_l vector has PPP-GDP weights that sum to one, corresponding to the interest rate shocks of each of the countries that belong to the selected region, and zeros elsewhere. For a global shock to interest rates, the vector has PPP-GDP weights that sum to one, corresponding to the interest rate shocks of each of the $N + 1$ countries, and zeros elsewhere.

6.2 Estimated Shock Responses

In this sub-section, we discuss the dynamic responses of four countries/regions to the transmission of shocks from both internal and external sources. Generalized impulse response paths are presented over a 40 quarter horizon, with responses estimated using a sieve bootstrap procedure with 1500 replications. Estimated responses are presented for the median response, while standard error bands represent the 68% confidence interval. Across all shocks, GIRFs are found to stabilize long before the 40^{th} horizon period, suggesting that the GVAR is long-run stable, with persistence profile analysis confirming this result. Impulse response functions showing the time paths of the six shocks are presented in Figure A1 in the Appendix.

6.2.1 Shocks to US Interest Rates

The first shock we consider represents a change in the US short-term interest rate, equivalent to a shock increase of 25 basis points. In the US, while the effect of the rate increase on output is initially positive (Figure 1), the response has become significantly negative within three quarters of the shock. Peak output reductions of 1.1% of GDP are observed within eight quarters, and despite a minor rebound to the series over the following quarters, long run output growth remains negative (and significant) at -0.93%. The response of Irish output to the US interest rate shock is somewhat more muted in the short run, having declined by -0.56% after eight quarters, with the loss to Irish output estimated to be -0.60% and statistically significant in the long run. The response of euro area output is broadly similar to that of Ireland (-0.45% after eight quarters, and a long run decline of -0.53%). The UK economy is the least effected in terms of output response, with eight-quarter effects of -0.39% and persistent long run effects of -0.31% of GDP.

With respect to inflationary effects (Figure 2), broadly similar transition paths are observed across all four economies. In the US, the initial increase in output is mirrored by a transitory rise in the rate of inflation, up to the first quarter after the interest rate shock. This finding aligns with the literature on the prize puzzle in the US, where an unexpected monetary policy tightening is followed by an temporary increase in inflation (Christiano, Eichenbaum and Evans 1996; Sims 1992). From this point, inflation rates decline, with the response returning to baseline levels within two years. The long run response of US inflation is indistinguishable from zero, with the effect turning insignificant from quarter five onwards. For Ireland, the UK and the euro area, the contemporaneous effect on inflation is negative, turning positive in the two quarters following the shock.This lagged increase in inflation in the UK, Ireland and euro area is consistent with the contribution of the exchange rates on prices following a rise in the US interest rate. By appreciating the value of US dollar, contractionary monetary policy in the US may lead to an increase in the price of US exports for foreign importers, which in turn passes through to foreign price inflation. This effect may be strongest in Ireland, consistent with Ireland's role as a small open economy with the US as an important trade partner. For the UK, Ireland and euro area, inflation turns negative in the long run. Again this long run effect is strongest for Ireland, where the decline in inflation is estimated to be -0.13% and significant; UK and euro area effects are smaller (in absolute terms) at -0.03% and are not significant.

Finally, the response of long-term interest rates (Figure 3) is also broadly similar across the four economies under analysis. Contemporaneous responses are all positive and significant, with the largest impact of 0.05 percentage points observed in the US, while Ireland, the UK and the euro area all experience an immediate increase in long term interest rates of $0.01 - 0.02$ percentage points. For the US and the euro area, shocks remain significant up to quarter 7, after which point responses are statistically indistinguishable from zero. With the exception of the impact effect, UK and Irish long-term interest rate responses are not found to be significant at any horizon period.

6.2.2 Shocks to Chinese Output

Our next shock simulation examines the impact of a slowdown in the Chinese economy, equivalent to one percent of Chinese GDP. Across all three shocks (Figures 4 – 6), results are broadly consistent for the set of four economies under analysis, suggesting similar relationships and transmission channels between China and Western nations. Following the shock, output is initially unresponsive for all of the economies, with contemporaneous responses of less than 0.1 percent of GDP in absolute value. Following this response, output declines over a number of quarters, with peak declines of between -0.16 and -0.35 within $4 - 8$ quarters of the shocks occurring. For all economies, the peak negative responses are all estimated to be significant. Where the responses differ is in the degree to which output then recovers from this minimum point. In the case of the US, output rises steadily from quarter 4 to quarter 16, by which point the effect on output is an increase of 0.15% (but not significant). In contrast, the Irish response does not recover beyond baseline levels, due to the greater output losses observed in the short run. Similar results are observed in both the UK and the euro area; the response following the initial decline returns output growth closer to, but below, baseline levels, with neither long run effect resulting in growth rates statistically or economically different from 0.

Correspondingly, the inflation responses resulting from the Chinese output shock are all consistent with the domestic output responses. In all economies bar the US, inflation responses are initially modest, with minor declines in inflation rates returning to baseline levels within $6-8$ quarters of the shock. In contrast, US inflation declines initially, before rising over the following few horizon periods to become significant by quarter six. Across all economies, only US long run effects are found to be significant, with an estimated increase of 0.07 percent. Results for Ireland and the euro area are more modest at 0.04 and 0.02 percent, respectively, while no long run effect is found on the inflation rate in the UK response.

Again, consistent with the previous results from the shock, the increased domestic output and inflation rates resulting from the shock to Chinese output causes similar movements in the long-run interest rates of the four economies under consideration. In Ireland, the initial impact of the shock is moderately positive but insignificant; however, the response increases to 0.35 percentage points over the medium term and becomes significant, before declining to a persistent long-run increase of 0.03 percentage points. Similar transition paths and significance levels are observed in the other economies; where the long run effect ranges between 0.035 percentage points (the UK) and 0.05 percentage points (the US). Similar to the effect on inflation, no short or long run effects are found on UK long-term interest rates.

6.2.3 Shocks to UK Output

The third shock examined in this paper, representing a negative shocks to UK output growth equivalent to one percentage point of GDP, is presented in Figures 7 – 9. Following this initial impact of 1%, the UK economy declines by a further 0.35 percentage points over the following 6 quarters, at which point the effects of the shock are almost fully experienced by the UK economy, with the long run effect estimated to be -1.38 percentage points of GDP and significant. In comparison to this, while the impact of the shock is negligible in Ireland, output growth declines by 0.45% over the next four quarters. This decline is significant and permanent, with a long run reduction in growth of 0.45% estimated over the entire horizon period. Similarly significant results are found for the euro area, with output reductions of 0.19% after four quarters and 0.25% after 40 quarters. Contrastingly, the US response is more muted; the long-run decline in output estimated to be -0.05 percentage points, while results are not found to be significant at any point in the horizon period.

Turning to inflation, the decline in UK output results in a transitory spike in the inflation rate of 0.22 percentage points, which is found to be statistically significant. However, this effect declines over the next few quarters, with effects falling to 0.1% after four quarters. Long run effects are also significant, with the long run decline in the inflation rate estimated at 0.08%.This positive response for UK inflation suggests that the dominant shock to UK output over the data sample has been on the supply side. This finding may be reflective of declining growth in labour market productivity in the UK, which was substantially lower than trend over the last decade of the sample. Similar to the UK, the euro area is found to be affected significantly, with a long run increase in the inflation rate of 0.03% in response to the decline in UK output. In contrast to these results, there are no significant inflation effects observed in either Ireland or the US, in either the short or long run. Despite this lack of significance, the magnitude of the Irish inflation response is in line with that of the euro area. The lack of significance in Irish inflation is likely to be a result of the high levels of volatility in Irish prices throughout the early 1980s at a time when UK and US inflation, while high, were relatively stable.

Finally, the effects on long-term interest rates are found to be relatively more diverse across countries. In the UK, there is a contemporaneous decline in long-term interest rates of -0.02 percentage points, after which point rates overshoot their previous baseline values, before declining slightly to a long run level that is 0.005 percentage points above baseline. Euro area responses to the shock are initially more muted, but a significant rise of 0.02 percentage points above baseline is observed within four quarters. Rates then decline slightly over the remaining horizon period, with effects becoming insignificant after eight quarters. US rates rise significantly in the short run (0.013 p.p.), with long run rates remaining 0.01 percentage point above baseline levels, while Irish long-term interest rate responses are found to be neither statistically or economically significant over the forecast horizon.

6.2.4 Shocks to UK Exchange Rates

The fourth shock estimated in the GVAR model represents a shock depreciation in the Sterling-Dollar exchange rate, equivalent to a currency devaluation of 15%. Impulse responses are presented in Figures 10 – 12. Examining the impact on output, the immediate response of UK GDP shows no immediate change, although growth of 0.4%

percent is observed after four quarters, declining slightly to 0.36 percent after eight quarters. The long-run effect is estimated to be an increase of approximately 0.37 percentage points of GDP, although this effect is not found to be significant. Similarly, the Irish output response to the exchange rate depreciation involves a peak increase of 0.5% after two quarters, declining to baseline levels over the next 8 quarters. Responses in the euro area are negative (but insignificant) over the horizon period, declining to a long run level of -0.36%. Finally, the US output response shows the greatest degree of significance; impact effects are small, but peak losses of -0.6% are observed after 10 quarters, with long run losses found to be significant.

Examining the effects of the exchange rate depreciation on inflation, a puzzle emerges. Despite the improvement in the UK terms of trade resulting from the depreciation, inflation rates decline in the UK following the shocks, with a reduction of -0.2 per cent on impact, and a persistent long run effect of -0.04 per cent. While surprising, similar results have been suggested by Forbes, Hjortsoe, and Nenova (2015) in response to a negative demand shock-induced depreciation: the paper finds a 10% appreciation of the exchange rate leads to a decline in inflation of -0.3% initially. They argue that this result may be due to non-credible monetary policy; if agents doubt the perisistance of exchange rate movement, they will be unwilling to adjust prices in response. Again, Ireland and the euro area are strongly affected by the depreciation, with small initial declines increasing in scale within four quarters of the shock. Responses are short and long run significant in both regions, with respective effects of -0.28% and -0.11% over the full horizon. In the US, significant impact effects (0.19%) return towards zero within five quarters, beyond which horizon point results are not found to be significant.

Finally, the effects of the shock on long-term interest rates are broadly consistent across regions. In the UK, Ireland and the euro area, the observed deflation causes a persistent decline in interest rates, with impact an long run effects of -0.07 percentage points (Ireland), -0.05 percentage points (UK) and 0.02 percentage points (euro area). Results are short and long run significant for all three economies. In the US, an impact response of -0.03 is observed in the quarter of the shock, although results quickly become insignificant.

6.2.5 Shocks to Global Output

The next shock to be analysed, presented in Figures 13 – 15, represents a simulated decline in global output, equivalent to a decline in total world GDP of one percent. For all four economies under analysis, the response path of the shock is found to be quite similar, with differences observed in the magnitude of the responses. For the UK, the US and the euro area, each economy suffers an immediate, significant decline in output in the period in which the global shock occurs, of between $0.39 - 0.67\%$ of GDP; the contemporaneous response in Ireland is negative, but not found to be significant. Over the following $4-6$ quarters, output declines to its peak loss levels in each economy, beyond which point there is a recovery in output, with long-run losses estimated to be between $40-80\%$ of the peak loss value. For the Irish economy, while there is almost no contemporaneous effect on domestic output, the peak effect of -1.37% of output is the largest loss observed for the set of four economies. Similarly, long run effects on Irish GDP are also considerable, with losses of -0.74% of output only matched by the euro area loss of 0.85% of output. It is also worth noting that the size of the error bands around the Irish impulse response is larger than those of the other economies, which may be reflective of Ireland's volatile economic position as a small open economy.

While output responses to a global shock are broadly similar in the four economies analysed, inflation responses are considerably more heterogeneous. Following the global output shock, there is a significant decline in the short run rate of inflation observed in the euro area, Ireland and the UK, with values ranging between 0.05 and 0.15 per cent. Long term inflation responses are positive for Ireland (0.05%) and the euro area (0.02%), and negative for the UK (-0.02%). In contrast, the contemporaneous response is negative in the US, with a decline of (-0.07%), before inflation rates return to baseline levels in the short run. In the long run, the inflation rate continues to rise between quarters 4 and 12, before rates stabilize at 0.15% above baseline levels, which is estimated to be significant.

Finally, long-term interest rates are again consistent in their response to the global economic downturn. While no economy experiences a significant contemporaneous response, long term rates are estimated to be significantly above baseline levels within four quarters of the shock for Ireland, the euro area and the UK, with effects ranging from an increase of between 0.04 and 0.07 percentage points. After this point, long run effects stabilize in Ireland, with long term rates 0.08 percentage points above baseline levels. In the euro area and the US, responses continue to rise up to 12 quarters after the shock, with significant long term effects of 0.1 (euro area) and 0.13 (US) percentage points above baseline levels. For the UK, short and long run effects are estimated to be positive, although these results are not significant at any point over the horizon period.

6.2.6 Shocks to Oil Prices

The final shock under analysis derives from the global variables in the VAR, representing the effect of a one standard deviation increase in the dollar price of oil, equivalent to a 12.6% price rise. Results from the GIRF analysis are presented in Figures 16 – 18. Across Ireland, the US and the euro area, there is an initial increase in output of between 0.05 and 0.30 percent in the first few quarters following the shocks, most likely representing valuation effects due to the increased input cost arising from the oil price increase. This increase lasts until quarter 5, beyond which point output growth becomes negative. Across all economies, peak negative responses occur $10 - 14$ quarters after the oil price shock, with output losses ranging between -0.21 and -0.33 per cent. Long run effects are estimated to be significant across all economies, with the UK the most affected (-0.32%) and the US the least affected (-0.20%).

Impulse responses of inflation to the oil price shock are in line with the output responses presented above. Consistent with the valuation effect resulting from the shock, inflation rates experience a positive, significant spike in the period of the shock for all economies, with values ranging between 0.11 percentage points (euro area) and 0.25 percentage points (US). Inflation then declines in all economies (only turning negative in the UK) over the following six quarters, at which point the majority of the impact of the shock is observed in all countries (there is some slight movement in the series for the UK and Ireland). Long run effects are found to be positive and significant for the US (0.05%), while Irish, euro area and UK responses are not significant in the long run.

Finally, the economic contraction caused by rising oil prices is found to drive up long-term interest rates across the four economies under analysis. The shock responses in Ireland, the US and the euro area are all broadly consistent, with impact responses of approximately 0.02 percentage points, and persistent long run responses of $0.012 - 0.018$ percentage points, although long run effects are not estimated to be significant. The UK differs in its response, whereby the shock response is somewhat smaller (0.011) than in the other economies, but still significant, with the response declining from impact to a long run effect of -0.003 percentage points that is not estimated to be significant.

6.3 Discussion of Results from an Irish Perspective

Examining the above set of shocks in relation to the Irish economy, some common trends begin to appear with respect to the domestic macroeconomic responses.

First, across all shocks presented in Section 7.2, the response of Irish output to the simulated shocks is consistently larger in magnitude than responses in the other countries under analysis. For the US short-term interest rate shock, the UK output shock, the China output shock, and the global output shock, the median Irish impulse response is consistently greater (in absolute value) than responses across the other three economies. While there are a number of factors that can account for this, the most likely explanation lies in Ireland's position as a small open economy. Of the four countries/regions under analysis, Ireland has the least diversified economy, the smallest domestic market, and the greatest reliance on international trade. Consequently, the relative magnitude of exogenous economic and financial shocks is likely to always be larger than in the three other regions. Additionally, the error bands surrounding these responses are typically larger for the Irish responses than in other countries, again suggesting a greater degree of uncertainty resulting from external economic shocks as a consequence of being a small open economy.

Second, across the set of shocks, the initial impact of a shock and the transition path of estimated responses for the Irish economy typically mirrors the UK response to a greater extent than the euro area response. While there is generally broad similarity in the impulse responses of all countries/regions across the set of estimated shocks, when transition paths do differ, it is more likely that the Irish response will appear more qualitatively similar to the UK response than responses in the US or euro area. Irish output responses to a UK output shock, long-term interest rate responses to a UK exchange rate shock, inflation responses to a US short-term interest rate shock all bear greater similarities with the impulse responses of the UK than to either the euro area or the US responses. This may, in part, be reflective of the interconnectedness of the two countries, the overweighting of the financial sector in both countries, the similarities in domestic economic policy, or the similarity of trading partner profiles.

Third, in line with its position as a small open economy, Ireland appears to be more exposed to the effects of shocks in the long run, than either the UK, the US or the euro area. Of the 18 impulse responses presented for each country in Section 7.2, 10 show significant long run effects on the domestic variable under analysis for the Irish economy. In contrast, only seven responses are long run significant in the UK and the euro area, while just eight are long run significant in the US. Again, this may reflect the inability of the Irish economy to appropriately adapt either economic policy or industry-mix in response to changes in external conditions.

Overall, the results suggest that domestic responses to external, exogenous shocks in Ireland are broadly similar to equivalent responses in the euro area, the UK and the US. While the directional effects and general transition paths are similar, Irish responses do exhibit a greater degree of amplification, relative to the other economies; unsurprising given Ireland's status as a small open economy that is heavily reliant on international trade. The long run significance of the majority of responses suggest that Ireland's ability to mitigate the effect of external shocks is limited, through either policy responses or structural/sectoral adjustments to the composition of the domestic economy.

7 Conclusion

This paper develops a macroeconomic GVAR model to analyse the effects of international linkages across countries, with a particular focus on Ireland and its main trading partners. The model uses international trade linkages to identify foreign relationships among countries, allowing for the transmission of exogenous, foreign shocks to domestic economies. Constructing the euro area from the eight core countries, the model provides a basis for both the identification of the effects of external shocks to Ireland, and the differing response of Irish macroeconomic variables to exogenous economic shocks, relative to its trading partners.

Results from the impulse response analysis show that, for Ireland, the UK, the US and the euro area, there is a considerable degree of correlation in a number of macroeconomic series in their response to exogenous economic shocks. In response to the six exogenous shocks tested in the paper, domestic output series were found to exhibit a strong degree of co-movement, with only the magnitude of the shocks showing some differences across countries / regions. Similarly, long-term interest rate responses also showed considerable co-movement, particularly for the global shocks, the China output shock and the US short-term interest rate shock. Inflation showed somewhat less co-movement across regions and shocks, but results were still similar for the majority of shocks, particularly the global and Chinese shocks.

Examining the individual shocks, the US short-term interest rate shock was found to have significant effects on output in all four of the economies analysed. The 25 basis point spike in the US policy rate was estimated to result in a long-term output decline of between -0.31% (in the UK) and -1% (in the US). While impact effects of the shock were not considerable in any economy, all four economies showed significant long-run effects on output in response to the unanticipated rate hike.

Similarly, the simulated global economic decline was found to affect output growth in the short run, with significant declines in all economies in the six quarters following the shock. Additionally, the global output shock drives up long-term interest rates, with significant short and long-run effects across most economies, leading to increases in borrowing rates of up to 0.15 percentage points.

Focusing on Ireland, the impulse response functions suggest that, while exogenous shocks follow similar time paths to the other three economies under analysis, the magnitude of the effects is typically larger (in absolute value) than in the UK, the US or the euro area. This is most likely reflective of Ireland being a small open economy, with limited ability to mitigate the effects of economic shocks, combined with a less diverse economy than the other three countries/regions. Additionally, confidence bands around the responses are also larger in a number of the Irish impulse responses, suggesting a greater degree of uncertainty in response to external shocks, which again may be due to small open economy characteristics.

In terms of further research, there is scope to expand the financial component of the GVAR model, incorporating additional domestic financial variables to analyse cross-border macro-financial linkages, including shock propagation from global financial instability. Similarly, the incorporation of financial weights into the modelling process, so that financial interconnectedness between countries is accounted for when stacking the country-level VARX* models, may also enhance the estimation of cross-border transmission mechanisms. Finally, there is potential for applying the GVAR model to currency zone research, which may assist in accounting for some of the disconnect between exchange rates and national current account balances.

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Table 1: List of Countries and Regions

Individual Countries		Euro Area Region
Argentina	New Zealand	Austria
Australia	Norway	Belgium
Brazil	Singapore	Finland
Canada	Sweden	France
China	Switzerland	Germany
Ireland	Thailand	Italy
Japan	United Kingdom	Netherlands
Korea	United States	Spain
Mexico		

Table 2: Domestic-Foreign Elasticity Estimates

Country	gdp	cpi	eqty	irs	irl
Argentina	-0.115	-3.694*	1.027*	3.743*	
	0.257	0.556	0.283	0.417	
Australia	0.201*	0.383*	0.725*	0.571*	0.943*
	0.082	0.105	0.061	0.135	0.132
Brazil	-0.216	4.291*		-4.402*	
	0.281	0.911		1.244	
Canada	0.285*	0.638*	0.867*	0.329*	0.950*
	0.092	0.091	0.055	0.080	0.048
China	0.414*	0.651*		0.022	
	0.198	0.220		0.018	
Euro Area	0.425*	0.157*	1.055*	0.043*	0.705*
	0.079	0.044	0.055	0.018	0.072
Ireland	0.770	0.785*	0.825*	0.701*	1.041*
	0.545	0.223	0.114	0.246	0.159
Japan	0.558*	-0.011	0.755*	0.010	0.513*
	0.161	0.072	0.096	0.021	0.081
Korea	0.102	0.182	0.910*	-0.154*	0.165
	0.155	0.133	0.127	0.065	0.234
Mexico	0.024	-0.451		-0.263	
	0.226	0.544		0.442	
Norway	0.591*	0.991*	1.082*	0.064	0.793*
	0.198	0.201	0.079	0.094	0.101
New Zealand	0.217	0.554*	0.891*	0.278	0.535*
	0.152	0.164	0.088	0.209	0.156
Singapore	0.853*	0.144	1.261*	0.024	
	0.229	0.121	0.099	0.091	
Sweden	1.121*	0.677*	1.221*	0.324*	0.934*
	0.190	0.183	0.077	0.114	0.086
Switzerland	0.502*	0.405*	0.946*	0.152*	0.514*
	0.125	0.107	0.055	0.064	0.066
Thailand	0.487*	0.583*	0.905*	0.072	
	0.248	0.152	0.142	0.127	
United Kingdom	0.461*	0.758*	0.762*	0.113	0.673*
	0.125	0.150	0.045	0.086	0.115
United States	0.445	0.053			
	0.095	0.049			

Table 3: Average Pair-Wise Cross-Section Correlations, Variables and VARX* residuals

Country	gdp			cpi			eqty		
	level	diff	resid	level	diff	resid	level	diff	resid
Argentina	0.910	0.043	0.011	0.342	0.066	0.062	0.415	0.201	-0.015
Australia	0.981	0.192	0.050	0.439	0.132	0.024	0.664	0.557	0.007
Brazil	0.965	0.170	0.039	0.282	-0.011	-0.030			
Canada	0.978	0.250	-0.019	0.523	0.214	0.068	0.572	0.561	0.032
China	0.978	0.126	-0.079	0.166	0.088	-0.039			
Euro Area	0.973	0.305	-0.005	0.558	0.230	0.061	0.655	0.592	-0.133
Ireland	0.971	0.077	-0.038	0.450	0.087	-0.014	0.268	0.397	-0.048
Japan	0.913	0.190	-0.008	0.368	0.097	0.033	0.284	0.460	-0.063
Korea	0.972	0.181	0.037	0.377	0.024	0.039	0.554	0.382	-0.030
Mexico	0.964	0.186	0.042	0.281	-0.035	-0.007			
Norway	0.975	0.127	-0.011	0.451	0.134	0.043	0.648	0.535	0.016
New Zealand	0.968	0.161	0.049	0.409	0.093	0.045	0.021	0.453	-0.002
Singapore	0.979	0.240	-0.002	0.262	0.130	0.066	0.376	0.522	0.014
Sweden	0.975	0.253	0.034	0.545	0.163	0.061	0.629	0.559	-0.002
Switzerland	0.973	0.238	0.020	0.523	0.179	0.050	0.622	0.562	-0.009
Thailand	0.961	0.174	0.012	0.326	0.139	0.034	0.341	0.357	-0.027
United Kingdom	0.980	0.262	0.030	0.529	0.134	0.013	0.653	0.581	-0.024
United States	0.978	0.282	-0.058	0.505	0.256	0.041	0.625	0.599	0.010

Table 4: Average Pair-Wise Cross-Section Correlations, Variables and VARX* residuals

Country	rer			irs			irl		
	level	diff	resid	level	diff	resid	level	diff	resid
Argentina	0.352	0.114	0.056	0.516	0.048	0.032			
Australia	0.845	0.427	0.219	0.736	0.187	0.069	0.919	0.401	0.019
Brazil	0.803	0.224	0.058	0.482	0.022	-0.033			
Canada	0.846	0.372	0.164	0.783	0.214	0.118	0.933	0.389	-0.002
China	0.513	0.089	0.010	0.601	0.073	0.026			
Euro Area	0.832	0.472	0.319	0.792	0.192	0.069	0.928	0.467	-0.073
Ireland	0.797	0.451	0.312	0.765	0.149	0.041	0.857	0.335	-0.004
Japan	0.775	0.214	0.147	0.758	0.067	0.021	0.900	0.275	-0.057
Korea	0.844	0.291	0.101	0.694	0.056	0.040	0.868	0.062	-0.040
Mexico	0.770	0.096	-0.020	0.617	0.015	0.020			
Norway	0.869	0.497	0.322	0.734	0.055	0.008	0.902	0.323	-0.024
New Zealand	0.864	0.427	0.248	0.695	0.109	0.088	0.837	0.197	0.018
Singapore	0.851	0.433	0.228	0.673	0.075	0.039			
Sweden	0.839	0.457	0.289	0.799	0.104	-0.019	0.928	0.414	0.018
Switzerland	0.867	0.418	0.306	0.596	0.081	-0.037	0.821	0.389	0.024
Thailand	0.812	0.284	0.166	0.679	0.119	0.052			
United Kingdom	0.847	0.431	0.264	0.795	0.186	0.069	0.926	0.431	-0.019
United States				0.725	0.164	0.063	0.909	0.423	-0.008

Figure 1: Impulse Response of Output to US Short-Term Interest Rate Shock

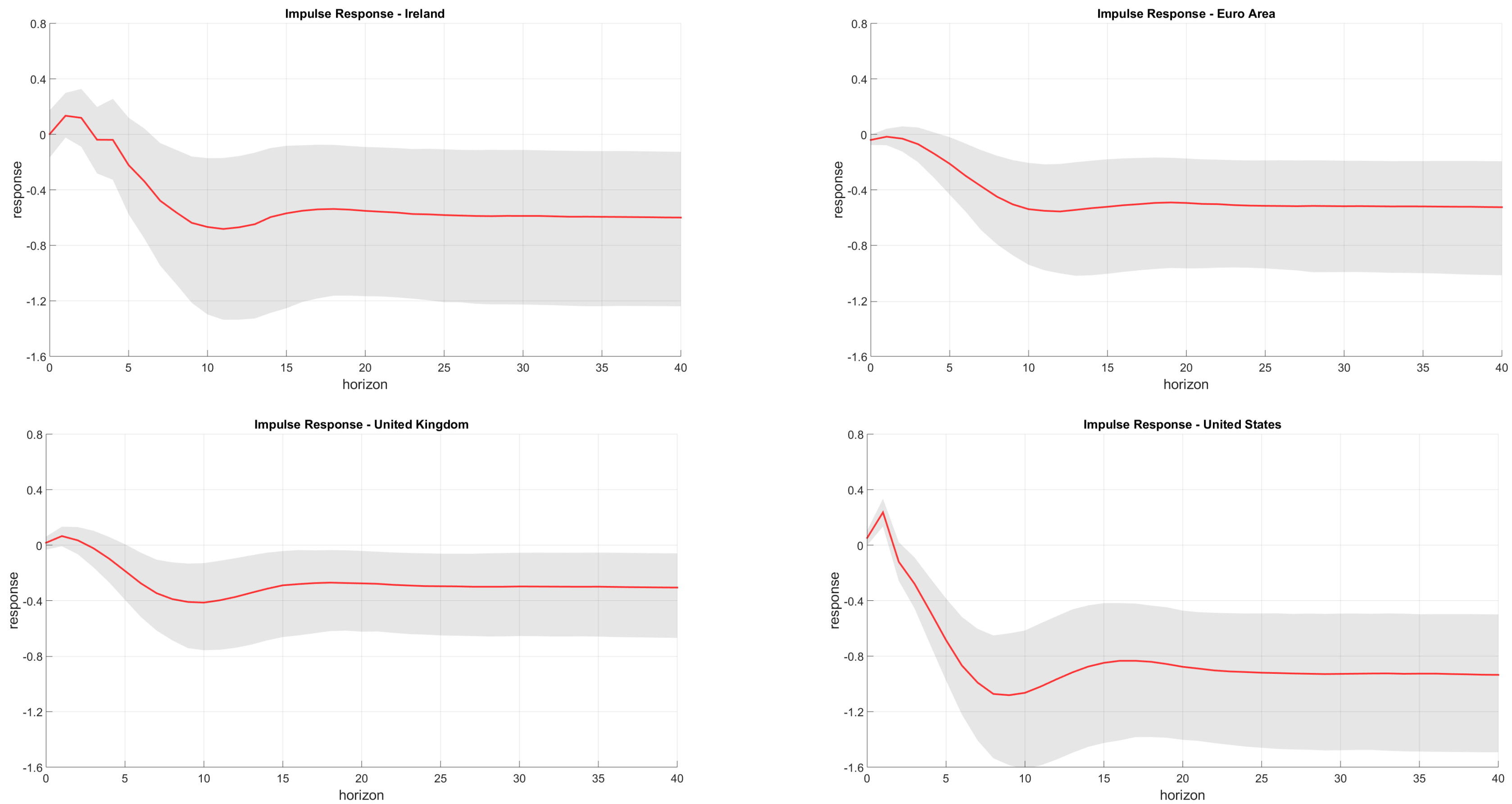


Figure 2: Impulse Response of Inflation to US Short-Term Interest Rate Shock

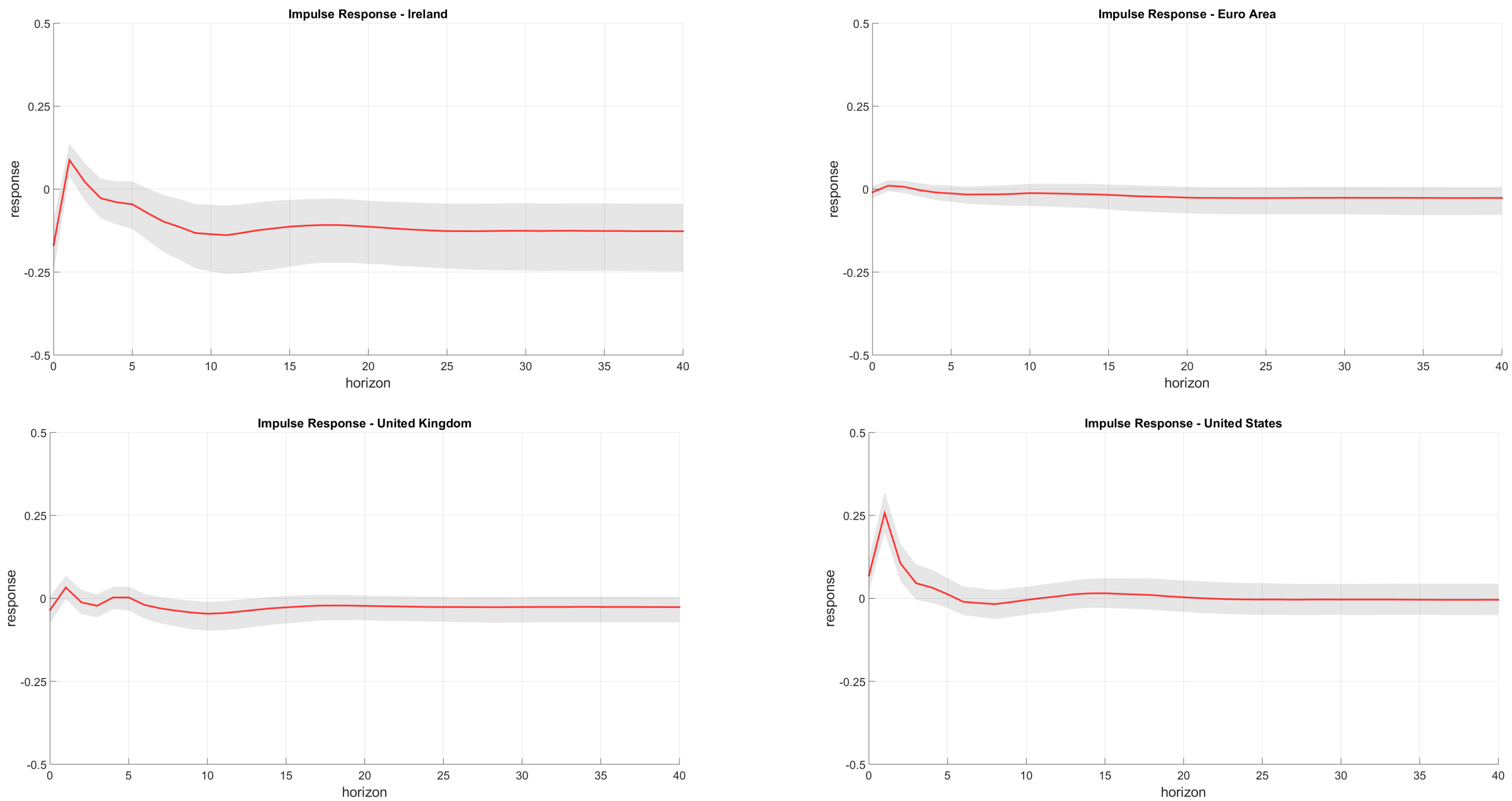


Figure 3: Impulse Response of Long-Term Interest Rates to US Short-Term Interest Rate Shock

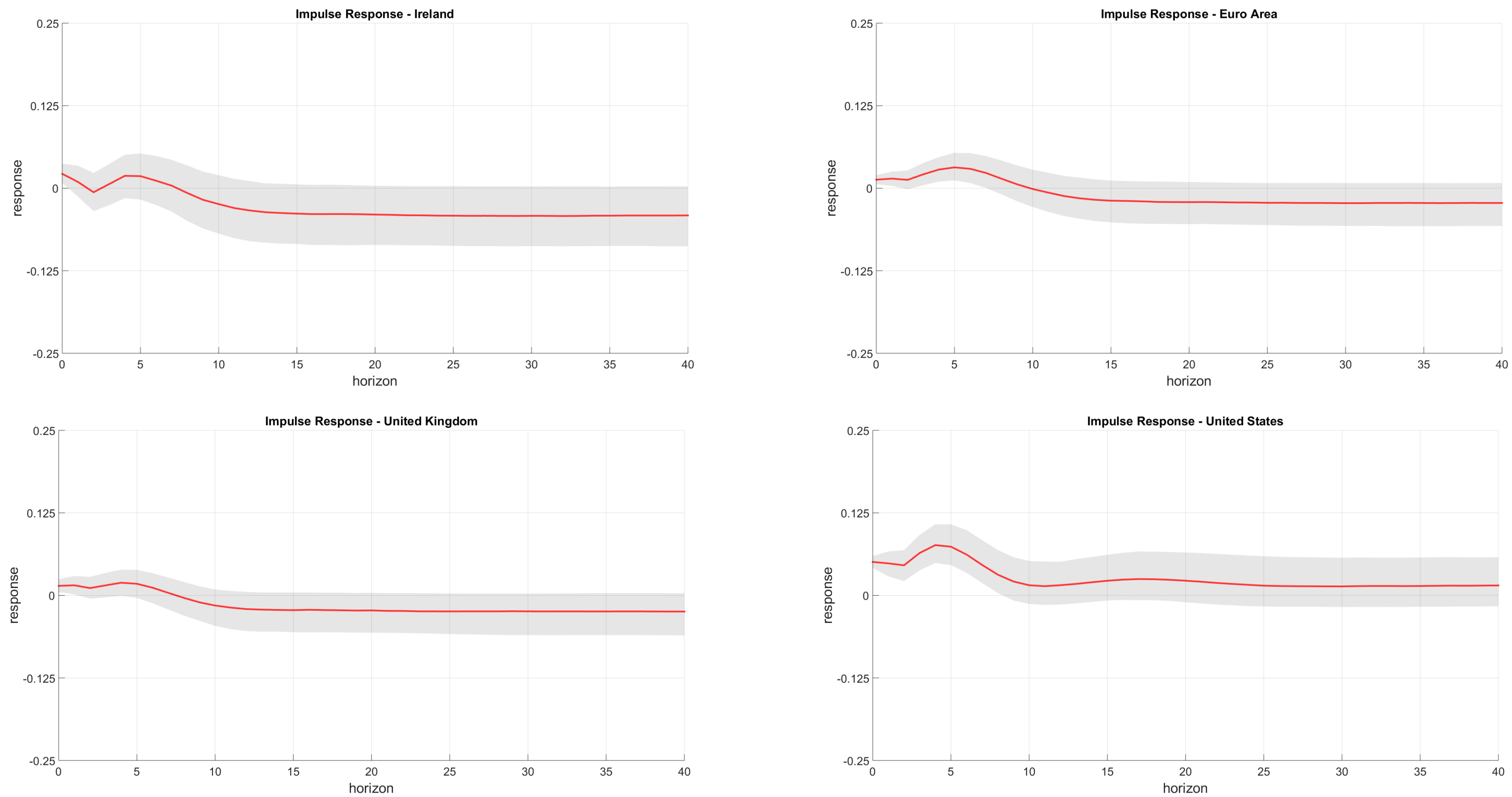


Figure 4: Impulse Response of Output to China Output Shock

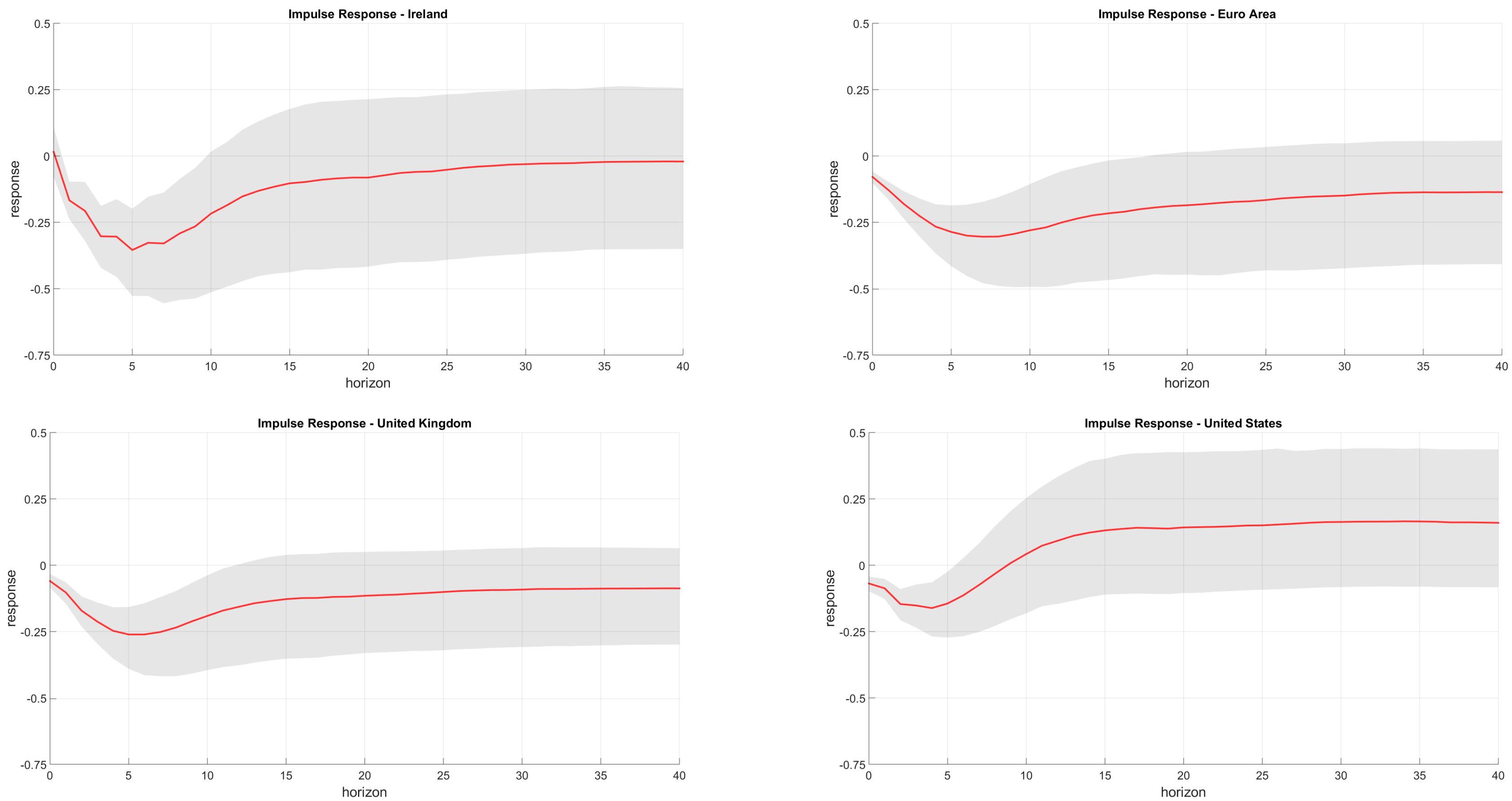


Figure 5: Impulse Response of Inflation to China Output Shock

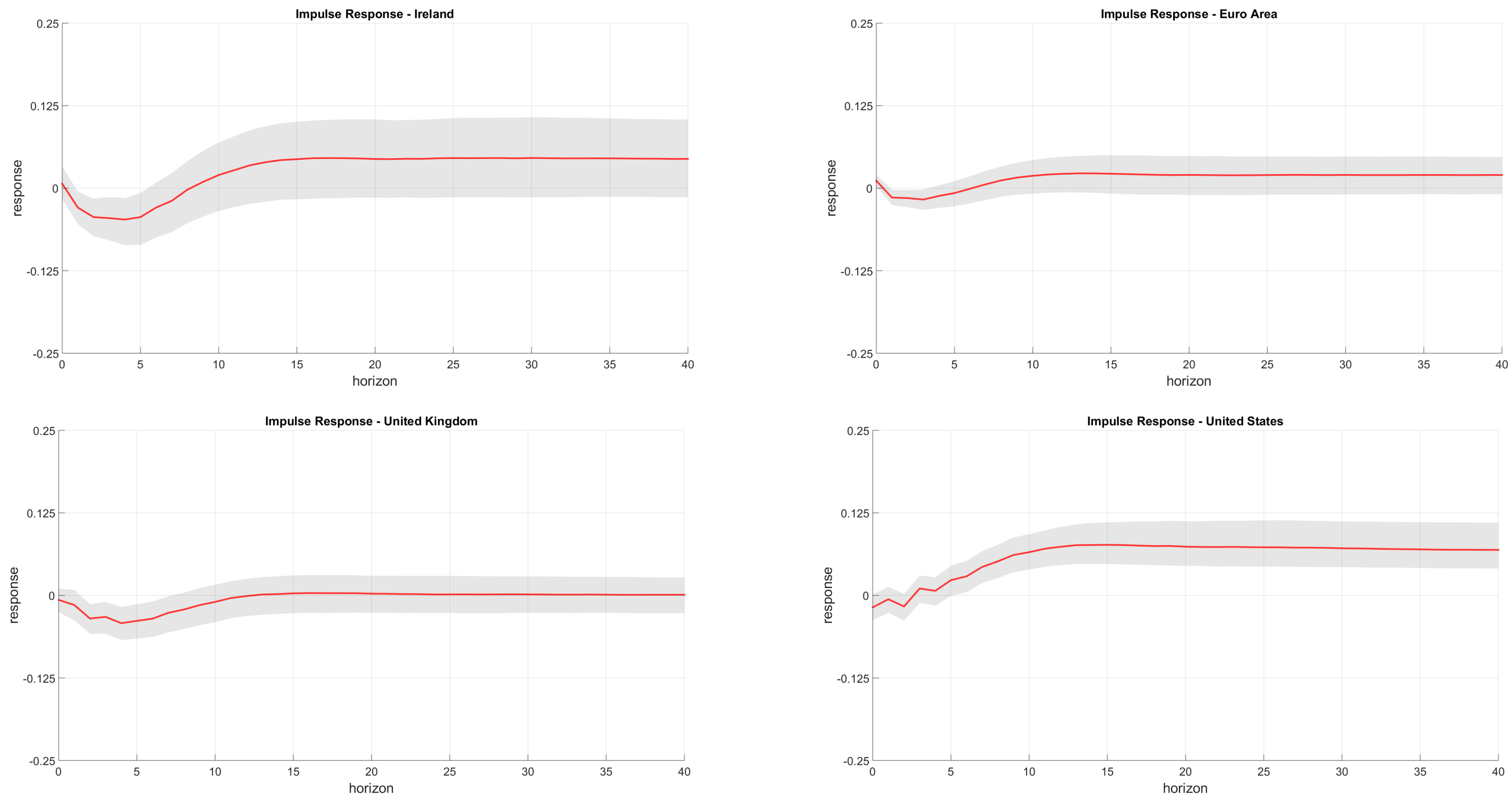


Figure 6: Impulse Response of Long-Term Interest Rates to China Output Shock

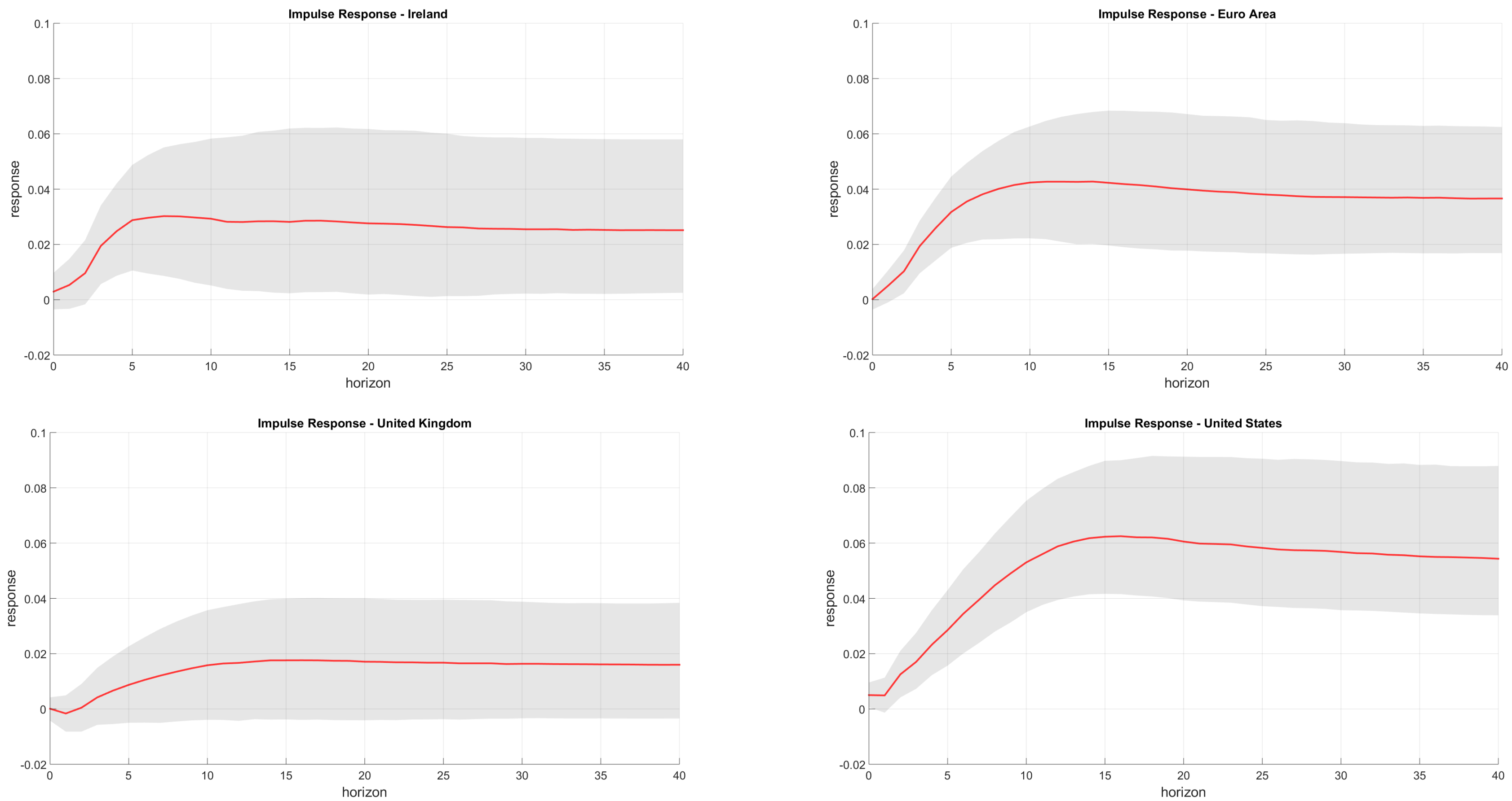


Figure 7: Impulse Response of Output to UK Output Shock

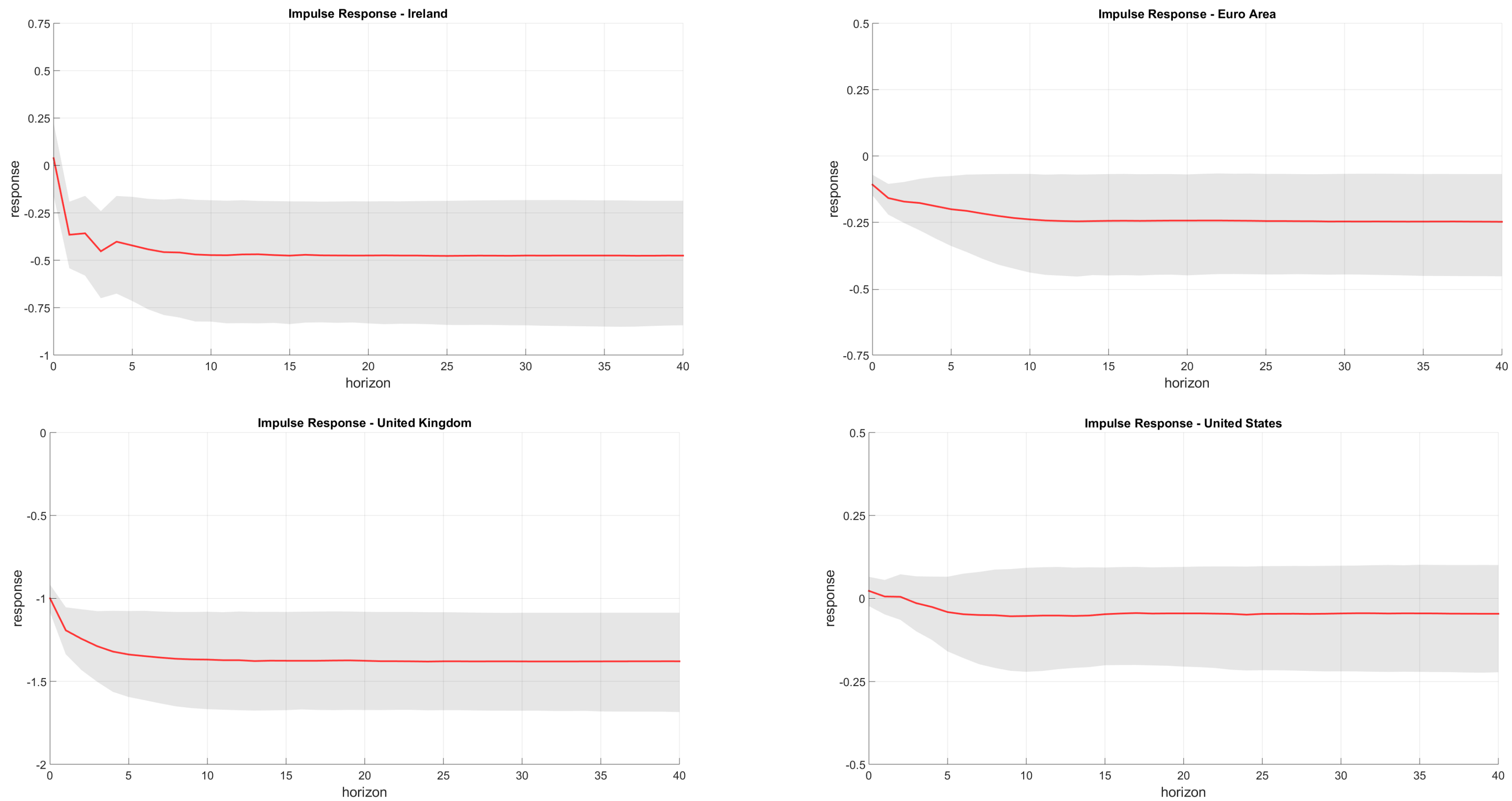


Figure 8: Impulse Response of Inflation to UK Output Shock

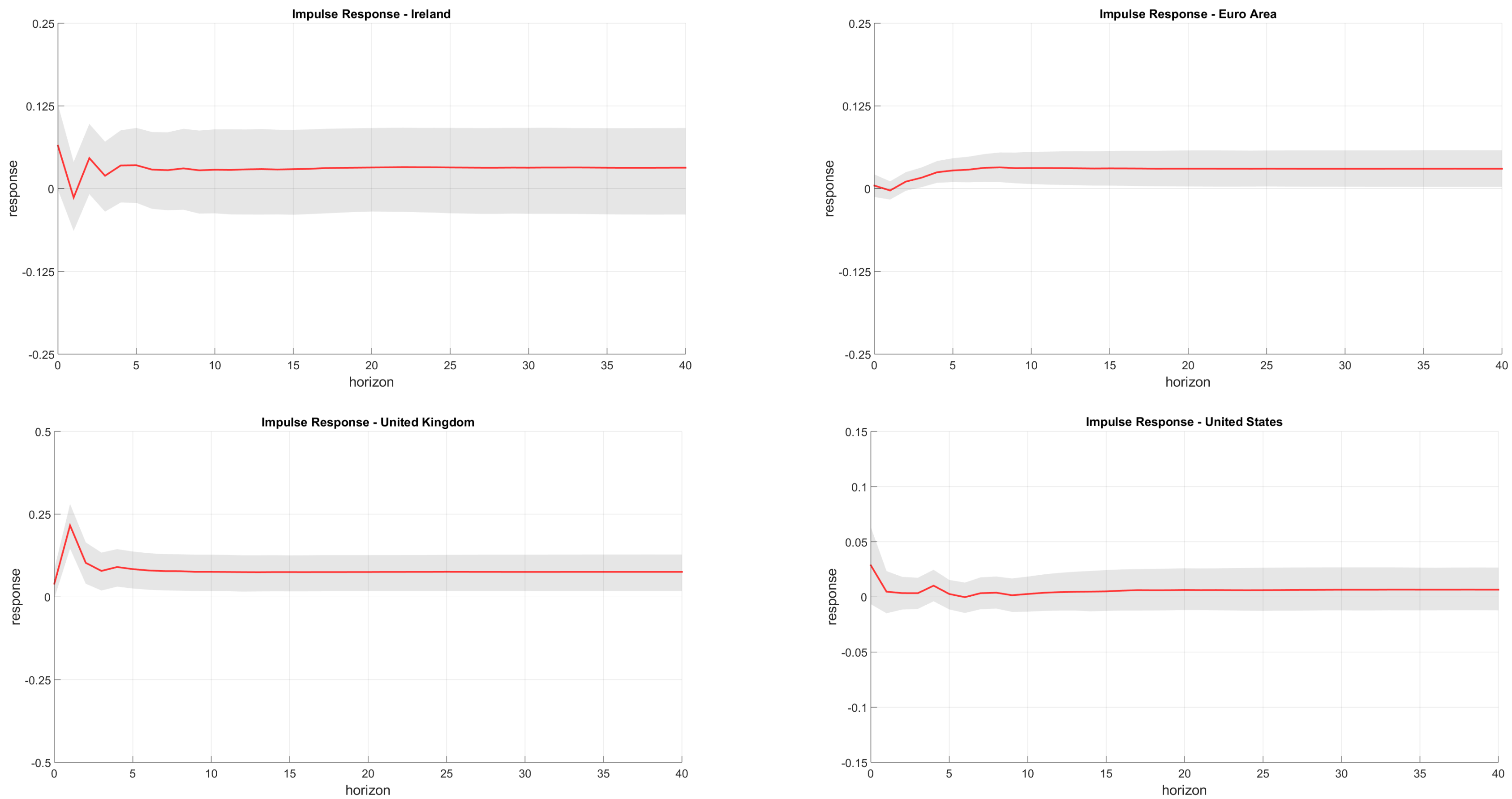


Figure 9: Impulse Response of Long Run Interest Rates to UK Output Shock

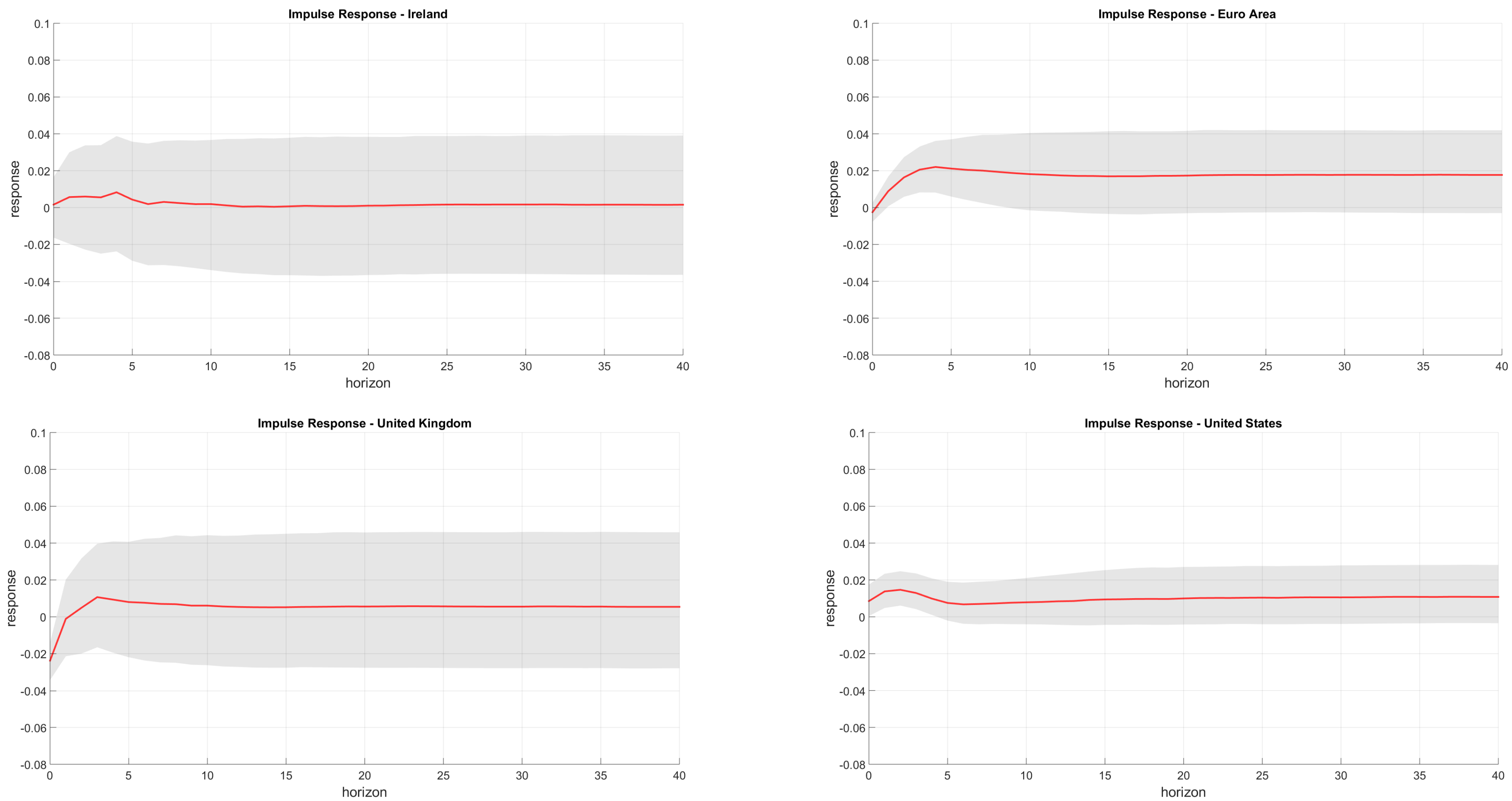


Figure 10: Impulse Response of Output to UK Exchange Rate Shock

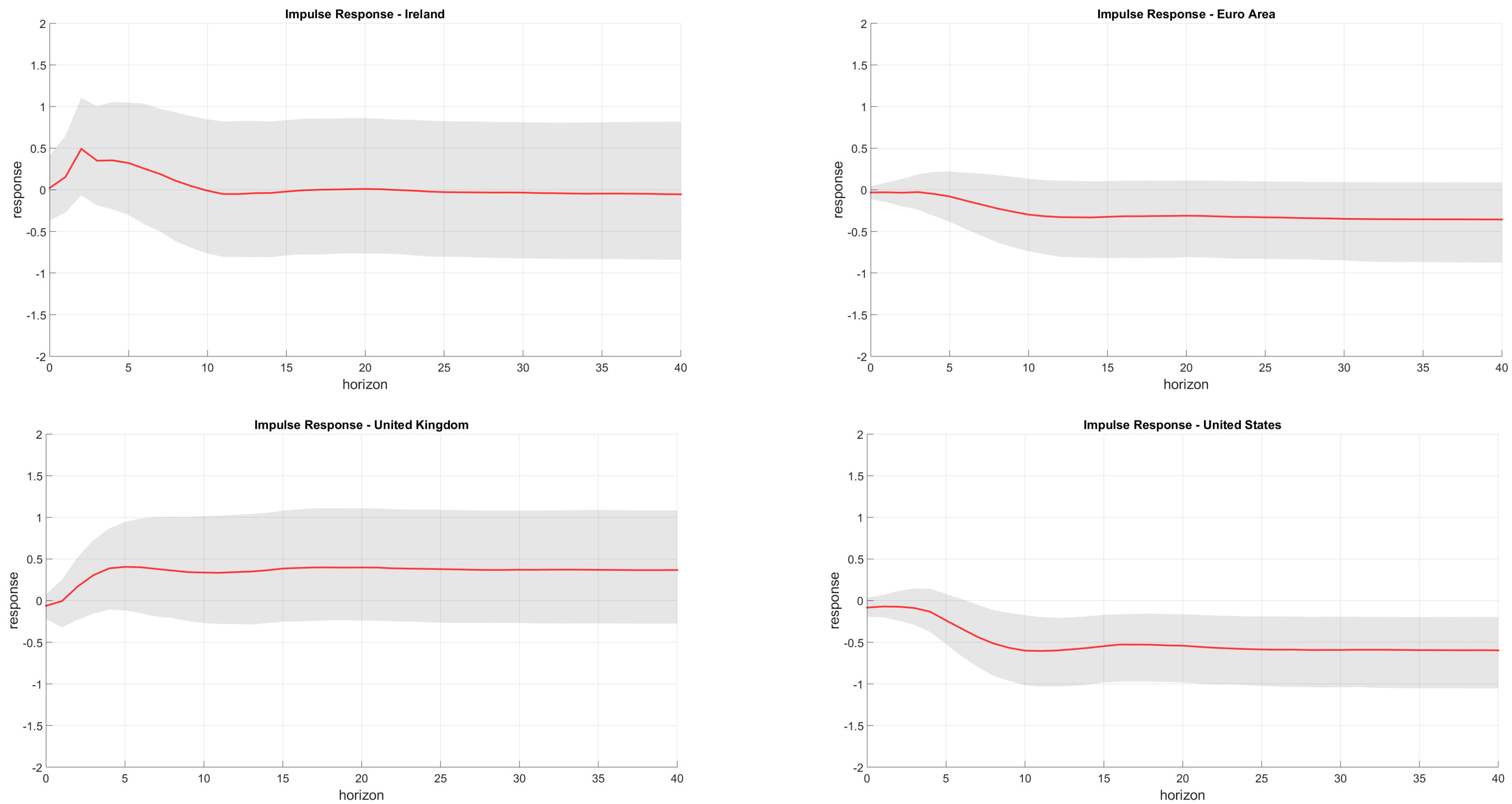


Figure 11: Impulse Response of Inflation to UK Exchange Rate Shock

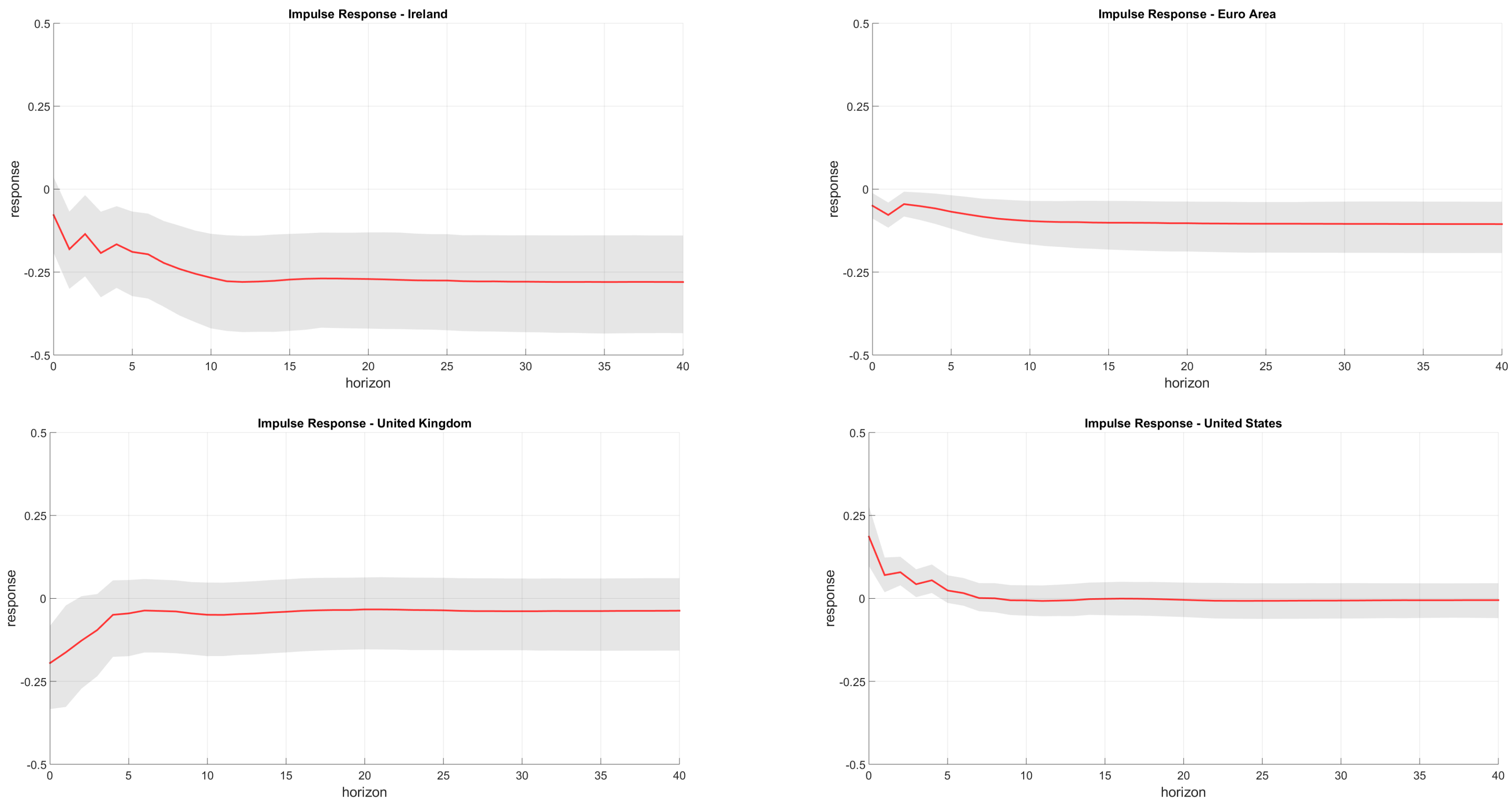


Figure 12: Impulse Response of Long-Term Interest Rates to UK Exchange Rate Shock

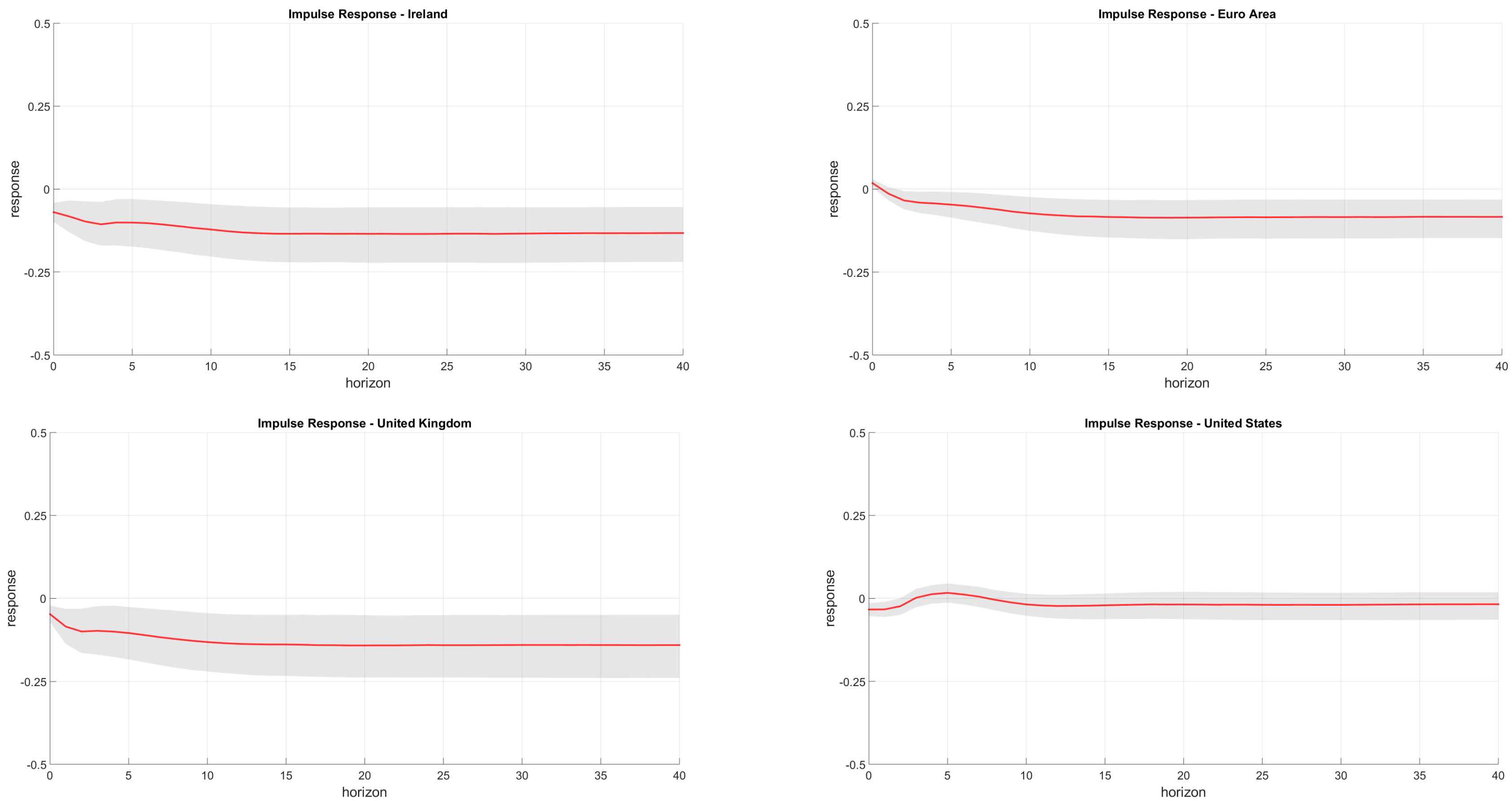


Figure 13: Impulse Response of Output to Global Output Shock

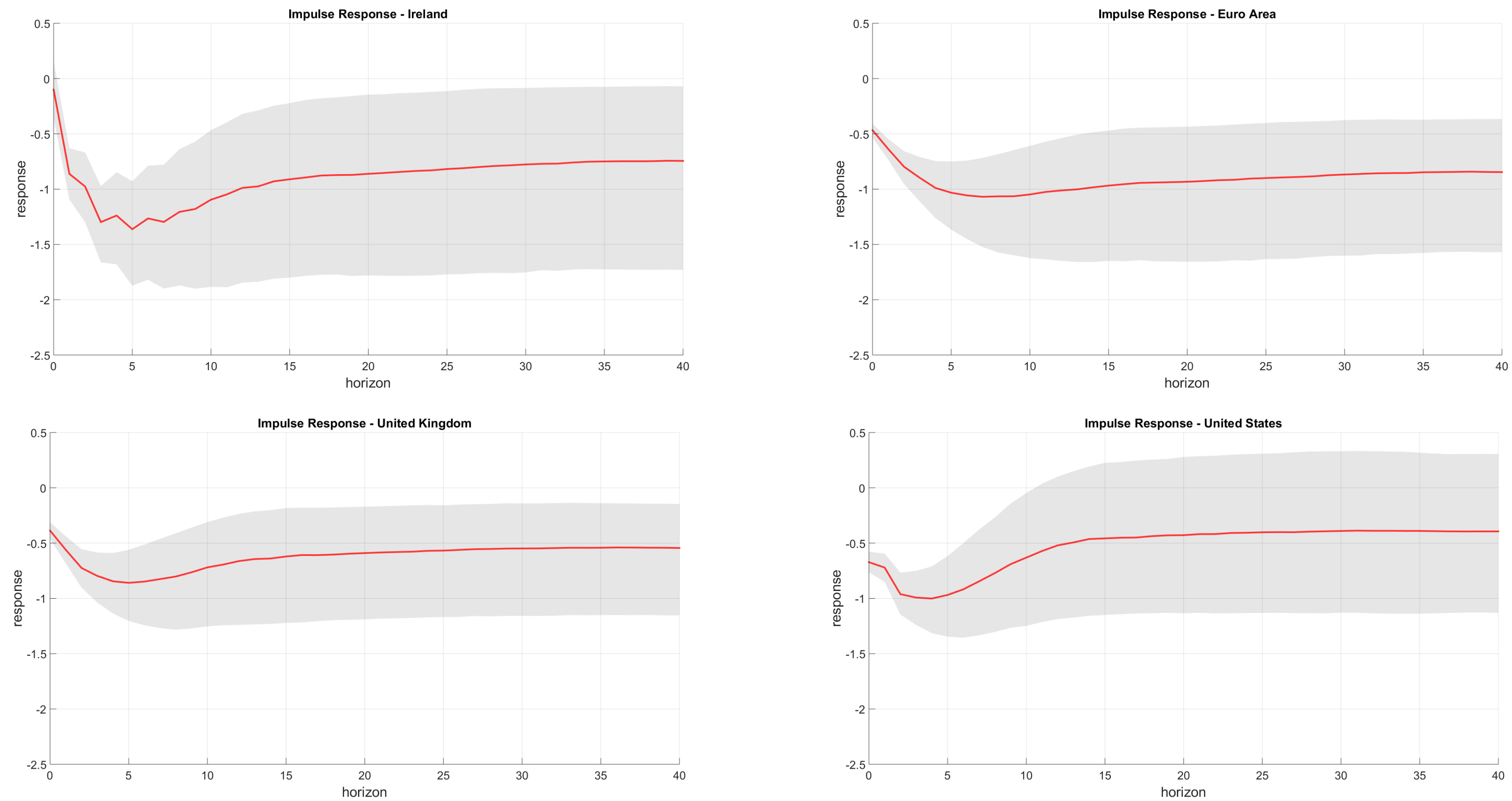


Figure 14: Impulse Response of Inflation to Global Output Shock

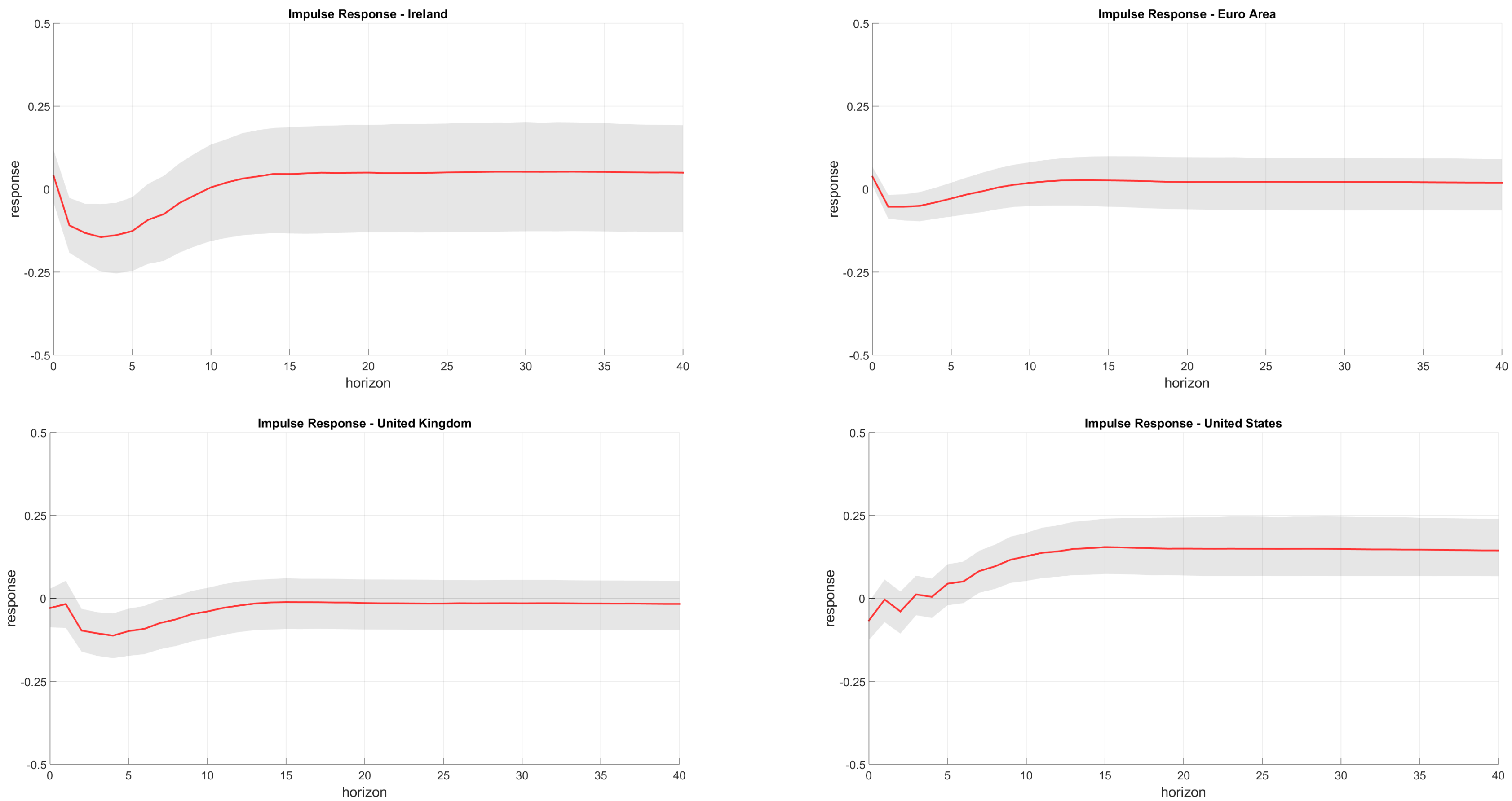


Figure 15: Impulse Response of Long-Term Interest Rates to Global Output Shock

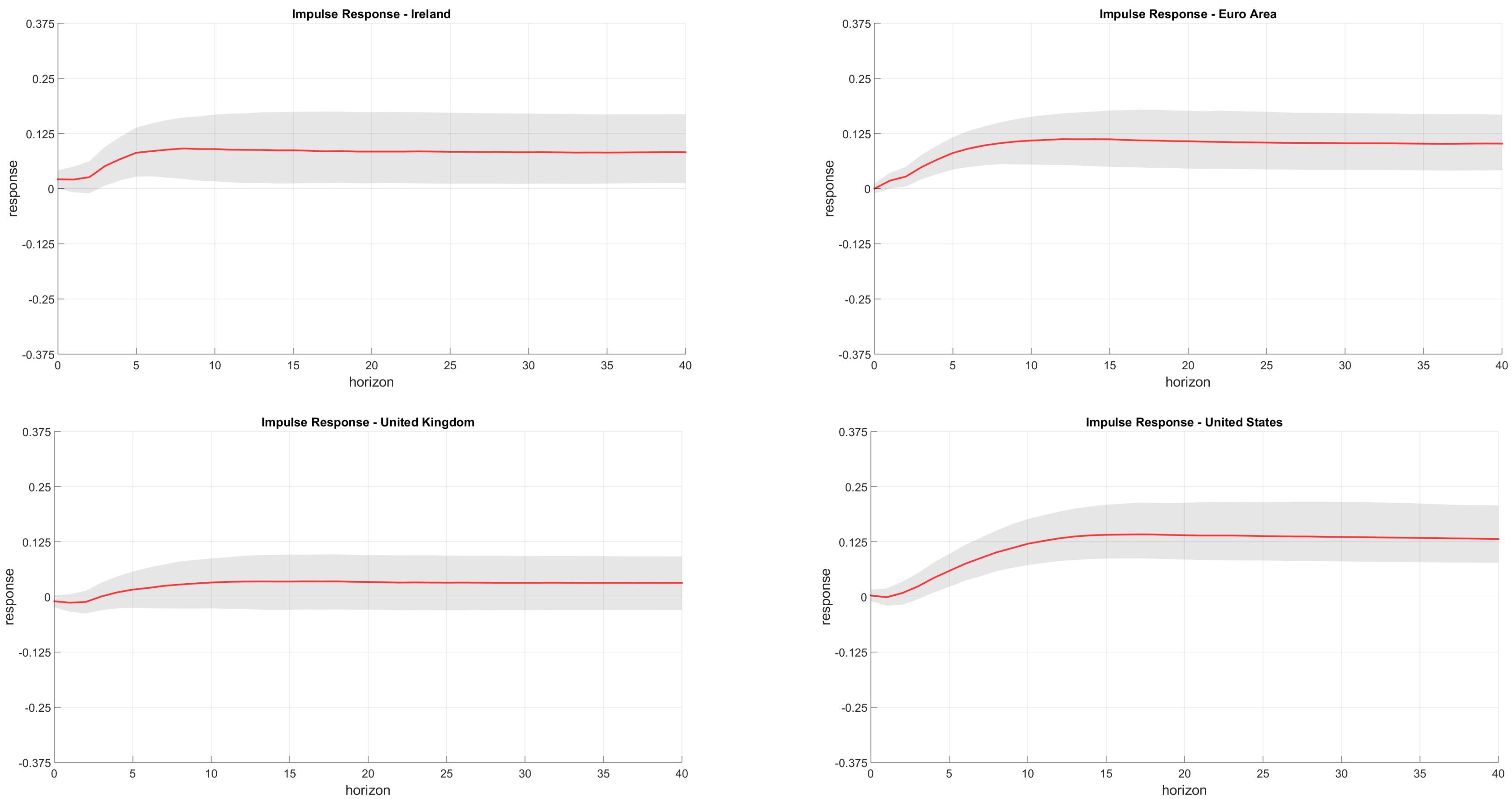


Figure 16: Impulse Response of Output to Global Oil Price Shock

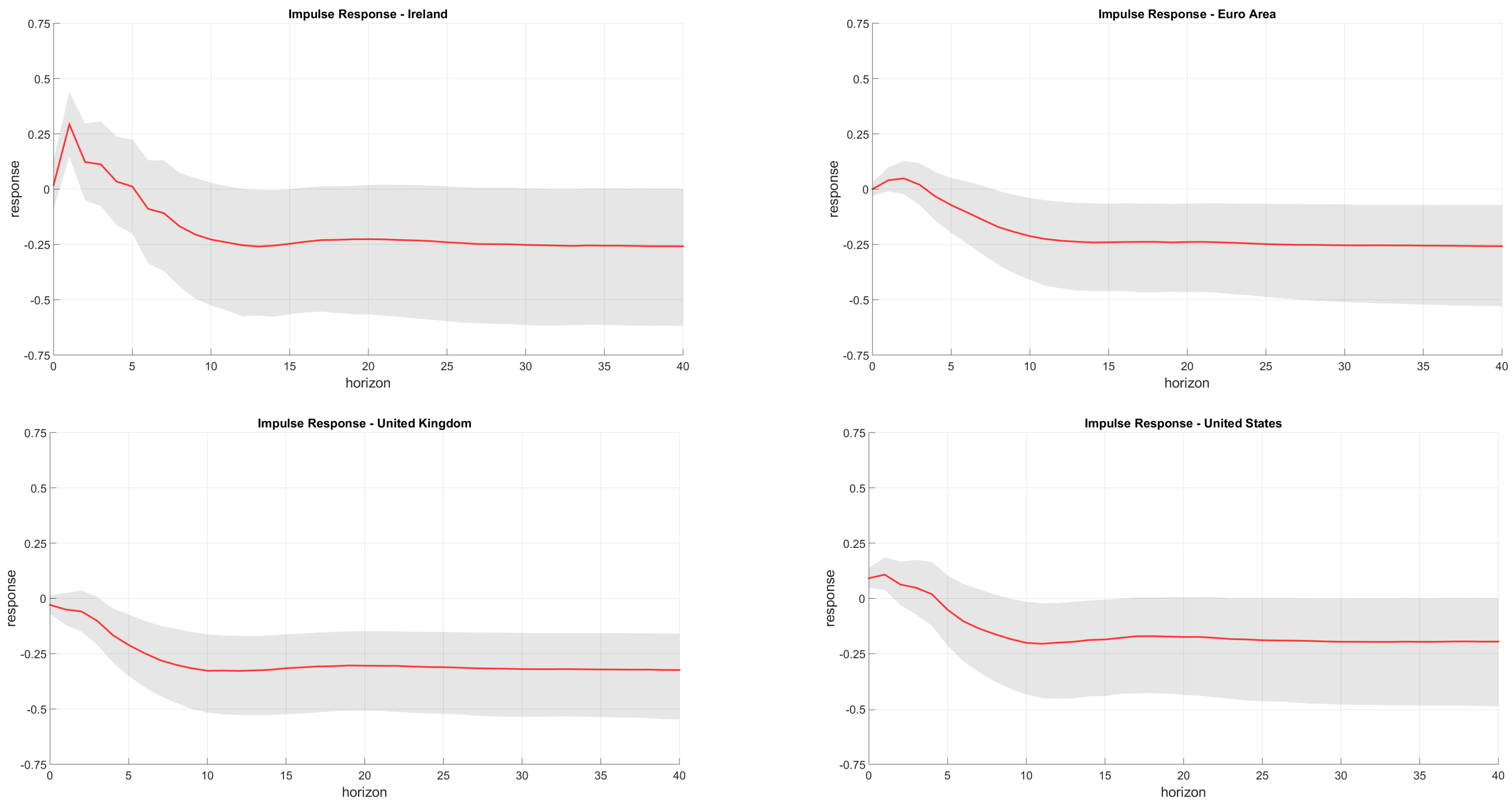


Figure 17: Impulse Response of Inflation to Global Oil Price Shock

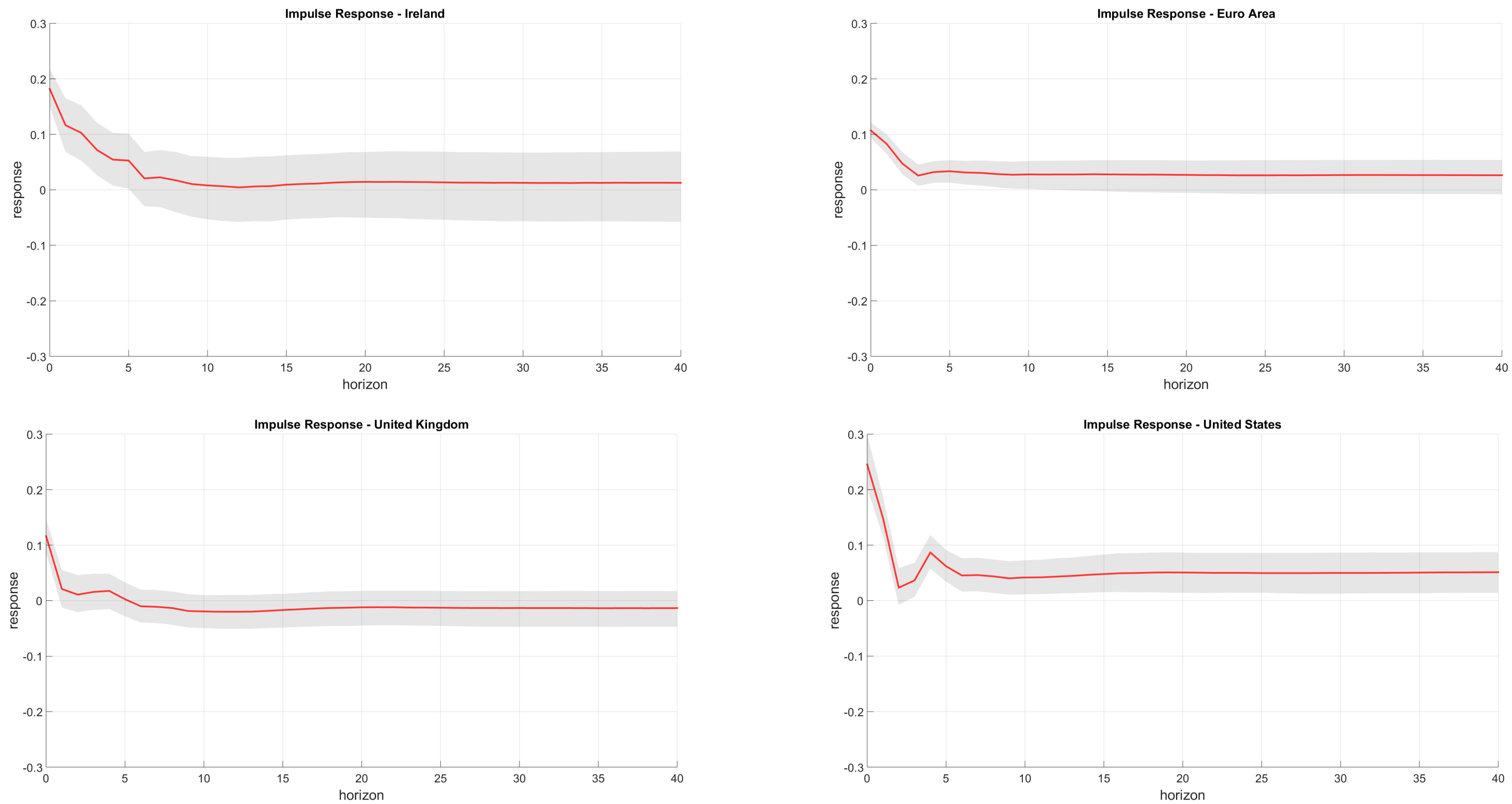
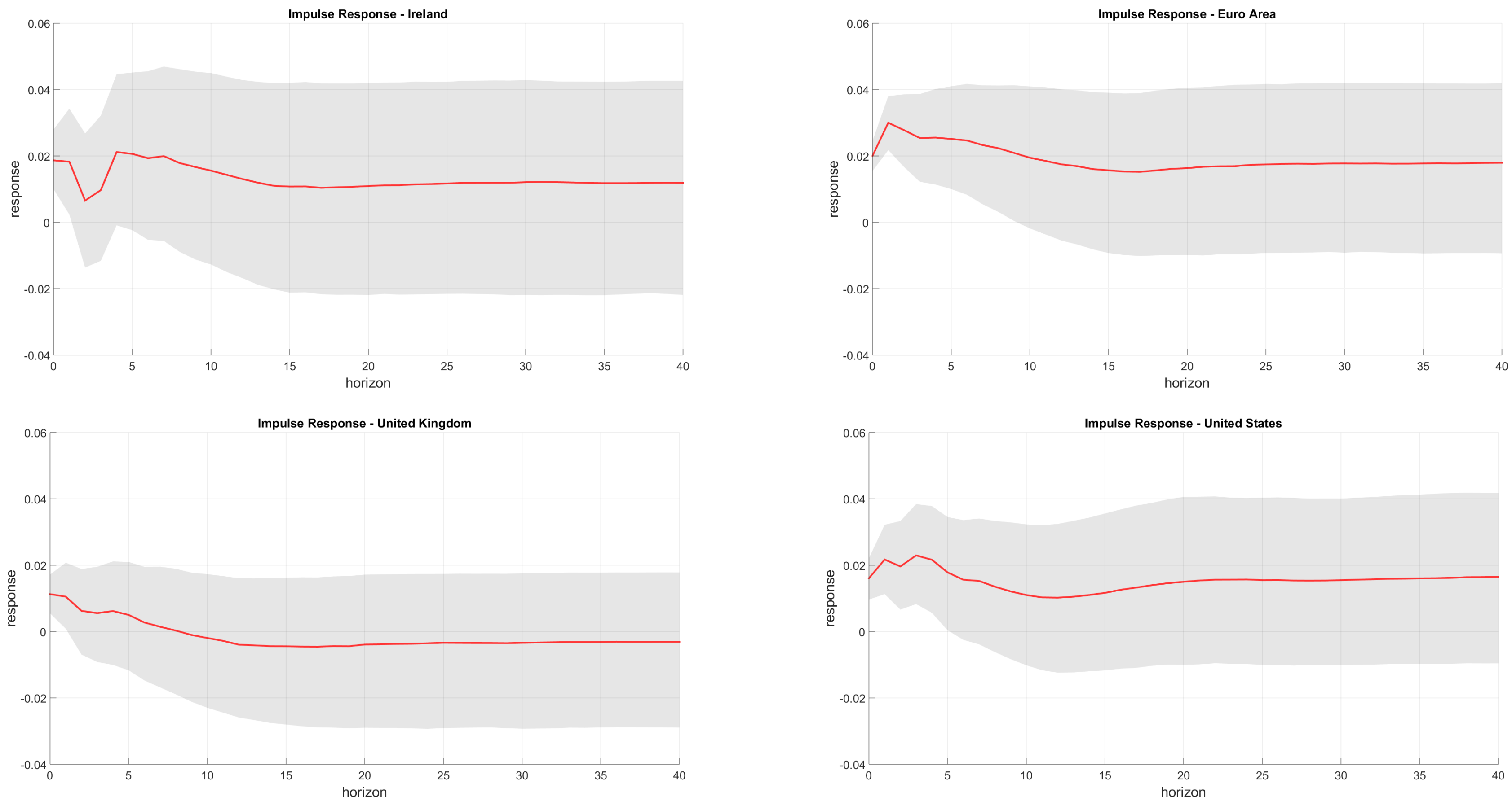


Figure 18: Impulse Response of Long-Term Interest Rates to Global Oil Price Shock



Appendix A: Model Specification and Testing

Given the complexity of the GVAR model, it is somewhat unsurprising that there are a number of specification settings that need to be determined prior to the estimation of the model and the dynamic analysis of the transmission of shocks across regions and countries. In this section, we discuss the main assumptions and specification settings underlying our model selection strategy, and present the results of tests of these choices.

A.1 Unit Roots Tests

While it is possible to apply the GVAR method to both stationary and integrated variables, we follow the assumptions of Dées, di Mauro, Pesaran and Shin (2007) and consider our variables to be integrated of order one, i.e. $I(1)$. Thus, the first test required of our data is to determine the integration properties of the domestic, foreign and global variable series in the model.

There are three main unit root tests that we consider employing in our tests: the traditional augmented Dickey-Fuller (ADF) test of Dickey and Fuller (1981); the generalized least-squares ADF (GLS-ADF) test proposed by Elliot et al. (1996); and the weighted symmetric estimation of ADF regressions (WS-ADF) test suggested by Park and Fuller (1995). We choose the WS-ADF approach as our test criteria for a number of reasons; principally, the WS-ADF test increases the power of conventional ADF tests by making use of the fact that any stationary autoregressive process possesses both a forward and a backward representation. Using Monte Carlo methods, Pantula, Gonzalez-Farias and Fuller (1994) examine the power of ordinary least squares, maximum likelihood, generalized least squares and weighted symmetric unit-root test criteria in finite samples, with the WS estimator found to be the most powerful.

The results of the WS tests in levels, first differences and second differences of the country-specific domestic variables are presented in Table A1, with the foreign variable counterparts presented in Table A2. In all unit root tests presented in these tables, the choice of lag length is determined by the Akaine Information Criterion (AIC), based on standard ADF regressions.

For the majority of countries in the sample, output, equity prices, real exchange rates, short-term interest rates and long-term interest rates are all found to be $I(1)$ in both the domestic and foreign variables of the VARX* models. There is a slight exception to our integration assumption with respect to inflation; for five of the countries in the sample (most notably China), inflation is borderline $I(0)/I(1)$ in the domestic variable tests. However, this is not the case for the foreign variable tests, where inflation is found to be $I(1)$ across all countries. Overall, the results from the WS-ADF tests generally support our unit root hypothesis for the country/region-level domestic and foreign data.

A.2 VARX* Model Specification and Estimation

With our assumption that country-specific foreign variables are weakly exogenous and $I(1)$, we impose one additional assumption and consider the parameters of the individual VARX* models to be stable over time. This assumption allows for the estimation and testing of long-run properties of each individual model separately and, when combined with the weak exogeneity assumption, allows for the initial estimation of the system-wide GVAR model.

Due to data restrictions and theoretical justifications, we allow for differing specifications across the VARX* models. For our euro area region, Ireland, the UK, Switzerland, Norway, Sweden, Japan, Canada, Australia and New Zealand, we include the full set of domestic variables $(gdp_{i,t},\ cpi_{i,t},\ eqty_{i,t},\ rer_{i,t},\ irs_{i,t},\ irl_{i,t})$ as endogenous and the full set of foreign variables, with the exception of the real dollar exchange rate, $(gdp^*_{i,t},\ cpi^*_{i,t},\ eqty^*_{i,t},\ irs^*_{i,t},\ irl^*_{i,t})$, as weakly exogenous to the model. Additionally, the global variables $(poil_{i,t},\ pmet_{i,t},\ pmat_{i,t})$ are also included in these models as being weakly exogenous.

For the US model, we exclude the domestic exchange rate variable from the set of endogenous variables, under the assumption that the US dollar exchange rate is determined outside of the US model, given the role of the dollar as the world currency, and include it in the vector of foreign variables. For China, Brazil and Mexico, we exclude real equity prices and long-term interest rates from the set of endogenous domestic variables, due to data not being available for these series. Similarly, we also exclude long-run interest rates from the vector of endogenous variables for Argentina, Singapore and Thailand. For the dominant unit model, we assume that feedback can only occur through global output and inflation, with global equity prices, exchange rates and interest rates having no influence on oil, metal and material prices.

With the vectors of endogenous and exogenous variables specified, we next estimate the VARX* models and determine the rank of their cointegrating space. To estimate the VARX*(p_i, q_i) models, where p_i represents lags of the domestic variables and q_i represents lags of the foreign variables, we let lag length be determined according to the Akaike Information Criterion (AIC). To maintain sufficient degrees of freedom, we constrain the maximum domestic lag length, p_i^{max}, to three and the maximum foreign lag length, q_i^{max}, to two.

Following the lag selection process, we then perform cointegration analysis, where reduced rank restrictions are imposed on the estimation of the country-specific models, leading to error corrections versions of equation (13). In keeping with the GVAR literature, we use trace statistics, rather than maximal eigenvalue statistics, to determine rank order, as they are known to yield better small sample power results. Table A3 presents the results of the lag order selection and cointegration tests. The most commonly observed model specification across the sample is a VARX*$(2, 1)$ structure, while most countries are found to have either two or four cointegrating relationships.

A.3 Weak Exogeneity Tests

As discussed in the beginning of this section, one of the key assumptions in developing the country-specific models that form the basis of the GVAR system is the requirement of weak exogeneity of foreign and global variables with respect to the long-run parameters of the error-correction form of the VARX* models

$$\Delta x_{i,t} = c_{i0} - \mu_i \nu_i' [z_{i,t-1} - \gamma_i (t-1)] + \sum_{j=1}^{p_i - 1} \Lambda_{i0,j} \Delta x_{t-j} + \sum_{k=1}^{q_i - 1} \Gamma_{i,k} \Delta z_{t-j} + \varepsilon_t \tag{21}$$

where $\mathbf{z}_{i,t} = (\mathbf{x}_{i,t}' \mathbf{x}_{i,t}^{*\prime})'$, μ_i is a $(k_i \times r_i)$ matrix of rank r_i and ν_i is a $((k_i + k_i^*) \times r_i)$ matrix of rank r_i.

For the purpose of estimation, $\mathbf{x}_{i,t}^*$ are considered to be weakly exogenous, or "long-run forcing" with respect to the VARX* model parameters. Country-specific VARX* models are estimated separately, conditional on $\mathbf{x}_{i,t}^*$, using reduced rank regression, taking account of the possibility of cointegration both within $\mathbf{x}_{i,t}$ and between $\mathbf{x}_{i,t}$ and $\mathbf{x}_{i,t}^*$. Using this approach, the number of cointegrating relations, r_i, the speed of adjustment coefficients, μ_i, and the cointegrating vectors, ν_i, for each country model are estimated.

Conditional on the estimate of ν_i, the remaining parameters of the VARX* model are consistently estimated by OLS based on the following equation

$$\Delta \mathbf{x}_{i,t} = \mathbf{c}_{i0} + \boldsymbol{\delta}_i ECM_{i,t-1} + \sum_{j=1}^{p_i - 1} \Lambda_{i0,j} \Delta x_{t-j} + \sum_{k=1}^{q_i - 1} \Gamma_{i,k} \Delta z_{t-j} + \varepsilon_t \tag{22}$$

where $ECM_{i,t-1}$ are the error correction terms corresponding to the r_i cointegrating relations of the i^{th} country model.

The weak exogeneity test performed on the country-specific VARX* models is based on the test set out in Harbo, Johansen, Nielsen and Rahbek (1998). This requires a test of the joint significant of the estimated error correction terms in auxiliary equations for the country-specific foreign variables. Specifically, for each l^{th} element of $\mathbf{x}^*_{i,t}$, we estimate the regression

$$\Delta x^*_{i,t,l} = a_{i,l} + \sum_{j=1}^{r_i} \delta_{i,j,l} E\hat{C}M_{i,j,t-1} + \sum_{s=1}^{p^*_i} \phi'_{i,s,l} \Delta \mathbf{x}_{i,t-s} + \sum_{s=1}^{q^*_i} \psi'_{i,s,l} \Delta \tilde{\mathbf{x}}^*_{i,t-s} + \eta_{i,t,l} \tag{23}$$

where $E\hat{C}M_{i,j,t-1}$ are the previously-estimated error correction terms corresponding to the r_i cointegrating relations from country $i's$ VARX* model. While p^*_i and q^*_i are the respective domestic and foreign variable lags, these need not necessarily be of the same order as the equivalent values chosen for the VARX* specification. The test for weak exogeneity is an F-test of the joint null hypothesis that $\delta_{i,j,l} = 0 \ \ \forall j = 1, 2, \ldots r_i$. Table A4 presents the result of the weak exogeneity tests.

Results from the weak exogeneity tests show that only three of the 160 variables reject the null hypothesis of weak exogeneity: global metal prices in the US; Norwegian foreign GDP; and UK foreign inflation rates. These results are encouraging, as the lag order $q^*_i = 1$ is selected by the Aikike information criterion for each country in the sample. Given that increasing the value of q^*_i typically decreases the number of significant outcomes for a country, the above tests can be considered the most restrictive form of the weak exogeneity tests. In particular, the fact that the exogeneity hypothesis is not rejected for any of the global variables, in any of the sample countries, is reassuring with respect to the chosen modelling strategy. Similarly, the possibility that aggregating the euro area countries into a single model could have violated the weak exogeneity assumptions is also rejected by the tests, further reinforcing our modelling approach.

A.4 Structural Stability Tests

As with any multi-country econometric model incorporating a time dimension, there is a potential underlying issue of structural breaks within the GVAR framework. While the incorporation of foreign variables within the country-level VARX* models should alleviate this issue to some degree, due in part to the idea of ”co-breaking” (discussed in Hendry and Mizon (1998)). If a structural break in market A leads to spillovers in a foreign market, A^*, conditioning on foreign variables that account for the break in A may eliminate the issue of a structural break being identified in A^*. As the country-specific VARX* models are flexible enough to account for co-breaking, the GVAR may be more robust to the possibility of structural breaks than macroeconomic frameworks that rely on single-equation reduced-form models.

In determining structural stability, we examine a number of tests of short-run parameter stability based on the residuals of the individual country error correction models. As discussed in O'Reilly and Whelan (2005), there are at least two issues with applying asymptotics-based parameter stability tests, such as the sup-F test: the high persistence of explanatory variables and heteroskedasticity. In either instance, the derived asymptotic distributions can deliver poor approximations to the relevant finite-sample distributions. To account for these issues, we apply a sieve bootstrap procedure in order to generate critical values for the test procedures. The set of test procedures consists of ten tests: the Ploberber and Krämer maximal OLS CUSUM statistic (PK_{sup}); the mean square variant of the maximal OLS CUSUM statistic (PK_{msq}); the Nyblom statistic ($\mathcal{R}$); the heteroskedasticity-robust Nyblom statistic ($\mathcal{R}_{rb}$); the Wald form of the Quandt likelihood ratio statistic (QLR); the heteroskedasticity-robust form of the Quandt likelihood ratio statistic (QLR_{rb}); the mean Wald statistic (MW); the heteroskedasticity-robust Wald statistic (MW_{rb}); the exponential average Wald statistic (APW); and the heteroskedasticity-robust form of the exponential average Wald statistic (APW_{rb}). Test results, aggregated at variable-level and presented in number and percentage of rejections of the null hypothesis of parameter stability, are presented in Table A5.

The results from the structural stability tests warrant some discussion. Principally, the results from the PK_{sup} and PK_{msq} tests show little parameter instability, with respective null hypothesis rejections occurring eight and three times out of the 98 potential instances. Neither test identifies breaks in the equity or exchange rate series; the two market segments in which "co-breaking" is most likely to occur. From these two tests alone, there seems to be limited statistical identification of the likelihood of structural breaks in the parameters of the model.

With respect to the variants of the $\mathcal{R}$, QLR, MW and APW tests, our results are comparable to Dees et al. (2007): the non-robust version of each test shows a considerably higher null hypothesis rejection rate than the equivalent robust form. For the non-robust variants of the four tests, the average rejection rate is 41.5%, suggesting a high degree of instability across the individual country models. However, across the four robust versions of these tests, rejection rates average just 13.66%. Once we account for heteroskedasticity in the variance of the error terms of the models, results are more in line with the PK tests, with parameter coefficients appearing relatively stable.

From this, we conclude that the identification of structural instability in the GVAR models is capturing changes in the error variances, rather than instability in the parameter coefficients. To account for this, we employ robust standard errors when identifying the effects of unanticipated shocks to the foreign variables, with our impulse response analysis based on sieve bootstrap mean values and standard error bands.

Appendix B: Data Sources

The GVAR dataset is quarterly in frequency and spans 145 periods, from 1980q1 to 2016q1. Data sources for the six variables forming the domestic and foreign components of the country specific VARX* models and the three variables forming the global aspect of the model are detailed below. Compilation of the dataset was aided by the Inter-American Development Bank (IDB) who extended, to 2013, the GVAR dataset used in Pesaran, Schuermann and Smith (2009a, PSS). In order to avoid inaccuracies due to potential revisions in the data, we independently gathered the data series for all countries in the GVAR, using identical data sources to those employed by the IDB to extend the PSS GVAR dataset. Where quarterly data from these sources was not available, or where annual data had originally been linearly interpolated, data from the original dataset were used up to 2008q1 and were extended to 2016q1, using extrapolation by growth rates. In each instance, however, we ensured that there was a minimum of five years overlap between the IDB dataset and our own, thereby enabling comparison of our data with the data contained in the IDB extended dataset. In doing so, we ensured that data were accurate and consistent, with minor differences occurring only as a result of small-scale data revisions. In the case of Ireland, which was not included in the original GVAR dataset, there was no option for data comparison, yet the data sources used remained consistent with the IDB.

The main source of data for real GDP was the IMF International Financial Statistics (IMF IFS). The IFS contains seasonally-adjusted quarterly Real GDP for Australia, Belgium, Canada, China, France, Germany, Ireland, Italy, Japan, Netherlands, New Zealand, Spain, Switzerland, United Kingdom, and United States. For the following list of countries, IFS does not report seasonally-adjusted data and therefore data were seasonally-adjusted using Eviews, via the United States Census Bureau's X-13 ARIMA-SEATS program: Austria; Belgium; Finland; Korea; Singapore; Sweden; Thailand; and Turkey. For the Latin American countries, namely Argentina, Brazil, and Mexico, the Inter-American Development Bank Latin Macro Watch (IDB LMW) database provided quarterly seasonally adjusted real GDP data.

The Consumer Price Indices data were sourced from the IFS. The following countries' series required seasonal-adjustment: Austria; Belgium; Canada; Finland; France; Germany; Ireland; Italy; Japan; Korea; Mexico; Netherlands; New Zealand; Spain; Sweden; Switzerland; Thailand; the United Kingdom; and the United States. Aside for China, seasonally-adjusted data were available for all of the remaining countries in the dataset. Since the IFS does not report CPI data for China prior to 2010, Bloomberg data were collected and seasonally-adjusted using Eviews.

Bloomberg was used to source the equity price series. A quarterly average of the local currency MSCI Index was obtained for all countries in the dataset. Quarterly averages were obtained by taking the simple average of the closing price of the last Wednesday of each month.

The exchange rate data were sourced from Bloomberg. Using the same process as with the equity price index, quarterly averages of nominal bilateral exchange rates *vis-à-vis* the US dollar were obtained for all countries. For the euro area member states, the exchange rates are identical post-1999. Pre-1999 however, for each member state, the euro exchange rate *vis-à-vis* the US dollar in 1999q1 was extrapolated backwards using the growth rate in each member states' national currency *vis-à-vis* the US dollar.

Short-term interest rate data were sourced from the IFS. Consistent with the IDB dataset methodology; the deposit rate was used for Argentina and China; the discount rate was used for New Zealand; the treasury bill rate was used for Canada, Mexico, Sweden, UK and US; and the money market rate was used for Australia, Brazil, Finland, Germany, Italy, Japan, Korea, Norway, Singapore, Spain, Switzerland, and Thailand. For Austria, Belgium, France, Ireland and the Netherlands there are no data from 1999 following the introduction of the euro, and therefore the German short-term interest rate was used as a proxy until 2011q2, from which point the IFS no longer published data on the German interest rate. From 2011q2 onwards, for these countries, the remaining data were extrapolated forward using the rate of change in the Euribor.

The IFS data on government bonds were used for all countries, where available. Importantly, where data is available it must be available for all periods in the dataset (i.e. from 1980q1 to 2016q1). Of the 25 countries in the dataset, there were five countries with missing data over this period: Argentina; Brazil; China; Mexico; and Singapore.

The oil price index was sourced from Bloomberg (daily, Brent crude oil prices) and converted into a quarterly series using the average of all trading days in each quarter. Monthly agricultural raw materials and metal price indices were obtained from the IMF's Primary Commodity Prices data. The quarterly series were calculated as simple 3-month averages of this monthly data.

The GDP$-$Purchasing Power Parity series from the World Development Indicator database of the World Bank, measured in current international dollars for 2012 to 2014, was used to obtain GDP weights for individual countries. The trade matrix was constructed using IMF Direction of Trade statistics (DoTs). Data on both imports and exports for all countries were collected at an annual frequency, and a 25×25 trade matrix was developed using averages of the exports and imports from the annual $2012 - 2014$ trade data.

Table A1: WS-ADF Unit Root Tests: Domestic Variables

VAR	ARG	AUS	BRA	CAN	CHN	EUR	IRL	JPN	KOR	MEX	NOR	NZL	SGP	SWE	CHE	THA	GBR	USA
gdp	-0.44	1.75	0.35	1.02	-0.27	0.79	0.59	1.72	1.09	1.49	1.28	1.48	1.76	0.93	1.60	2.06	0.61	0.99
d.gdp	-5.50	-6.64	-5.76	-5.41	-4.44	-5.02	-4.13	-6.86	-6.24	-6.50	-7.88	-7.03	-6.35	-7.04	-7.74	-6.24	-4.52	-4.73
dd.gdp	-10.58	-10.03	-9.56	-8.48	-12.11	-11.34	-11.18	-14.40	-11.04	-10.07	-10.88	-10.34	-9.39	-15.01	-13.31	-10.31	-11.46	-7.79
cpi	-2.76	-3.33	-3.31	-2.22	-3.31	0.83	-1.60	-1.66	0.16	-2.82	-1.76	-2.85	-4.22	-1.15	-3.75	-3.66	-0.49	-0.04
d.cpi	-13.44	-13.17	-9.59	-10.06	-7.62	-11.37	-8.18	-14.83	-6.03	-9.79	-14.30	-11.12	-9.14	-13.26	-9.19	-9.02	-7.85	-10.45
d.dcpi	-16.24	-10.99	-9.87	-11.75	-9.72	-11.99	-9.85	-11.85	-10.92	-14.86	-10.94	-10.74	-13.67	-10.91	-11.63	-13.81	-10.47	-12.26
eqty	-3.68	-1.28		-1.25		-0.74	-1.97	-1.48	-1.28		-1.47	-2.00	-4.00	0.40	-0.30	-1.61	-0.20	-0.03
d.eqty	-10.80	-7.83		-8.05		-7.89	-6.94	-8.00	-7.93		-8.44	-7.18	-8.64	-7.62	-8.34	-8.02	-9.03	-8.04
dd.eqty	-11.74	-10.84		-13.20		-12.24	-14.33	-9.53	-14.99		-15.02	-15.35	-11.72	-14.12	-12.28	-10.16	-11.35	-10.04
reer	-2.12	-0.68	-1.41	0.16	-0.85	-1.54	-1.43	-0.26	-0.91	-1.13	-0.83	-0.61	0.86	-1.54	-0.46	-0.93	-0.66	
d.reer	-7.90	-8.42	-8.65	-7.66	-7.64	-7.74	-8.10	-5.23	-8.48	-7.67	-8.03	-7.29	-7.07	-7.71	-8.26	-8.04	-8.90	
dd.reer	-10.07	-11.29	-11.20	-9.76	-11.70	-9.20	-9.15	-16.96	-10.21	-14.62	-10.59	-10.47	-9.81	-9.80	-14.83	-12.10	-10.36	
irs	-2.40	-1.83	-2.77	-0.57	-1.43	-0.73	-0.60	-0.98	-0.46	-1.61	-1.07	-1.86	-0.72	-1.12	-1.67	-1.93	-0.38	-0.09
d.irs	-17.27	-7.94	-11.75	-6.80	-6.57	-6.36	-12.19	-5.96	-9.90	-10.67	-9.16	-9.37	-6.92	-7.69	-8.85	-8.85	-7.61	-6.61
dd.irs	-14.10	-11.85	-12.37	-9.19	-13.12	-8.35	-10.56	-7.22	-10.34	-11.88	-12.74	-10.22	-8.95	-11.34	-10.28	-15.53	-9.72	-8.95
irl		-0.68		-0.10		-0.40	-0.53	0.43	0.85		-0.70	-1.02		-0.61	-0.78		0.11	-0.51
d.irl		-8.26		-8.11		-5.65	-7.73	-8.97	-8.68		-8.40	-8.09		-8.13	-8.22		-8.38	-7.62
dd.irl		-15.27		-7.02		-12.75	-8.26	-12.48	-10.63		-10.89	-9.96		-12.07	-13.10		-13.91	-12.84

Table A2: WS-ADF Unit Root Tests: Foreign Variables

VAR	ARG	AUS	BRA	CAN	CHN	EUR	IRL	JPN	KOR	MEX	NOR	NZL	SGP	SWE	CHE	THA	GBR	USA
gdp*	1.16	1.05	0.67	0.81	0.85	0.58	0.32	0.82	0.96	0.76	0.56	0.89	0.94	0.25	0.60	1.04	0.82	1.19
d.gdp*	-5.74	-4.89	-4.66	-4.83	-5.47	-4.55	-4.66	-4.67	-4.80	-4.88	-4.40	-4.88	-4.98	-4.43	-4.68	-5.21	-4.72	-5.77
dd.gdp*	-12.85	-10.89	-10.06	-7.43	-9.13	-8.87	-9.67	-10.80	-10.83	-7.45	-9.93	-10.51	-11.04	-10.41	-9.94	-10.41	-8.59	-9.03
cpi	-3.22	-2.31	-2.29	-0.07	-1.94	-1.91	1.34	-2.09	-2.26	-1.64	-0.63	-2.02	-1.78	-0.01	-0.64	-1.92	-0.57	-1.37
d.cpi	-9.56	-10.21	-14.08	-9.87	-9.44	-9.49	-8.65	-9.80	-9.71	-11.78	-10.18	-11.04	-9.97	-11.32	-10.48	-10.52	-11.12	-11.68
dd.cpi	-9.92	-10.59	-16.48	-12.21	-10.26	-11.19	-11.27	-11.32	-11.30	-11.73	-10.73	-10.87	-11.15	-10.36	-10.55	-11.07	-10.77	-15.27
eqty*	-0.39	-0.75	-0.93	-0.07	-0.46	-0.26	-0.33	-0.42	-0.57	-0.10	-0.32	-0.63	-0.43	-0.69	-0.58	-0.70	-0.68	-0.91
d.eqty*	-8.05	-8.06	-8.43	-8.06	-8.16	-8.12	-8.02	-8.37	-8.07	-8.08	-7.95	-8.10	-8.23	-7.91	-7.96	-7.98	-7.75	-7.90
dd.eqty*	-11.69	-14.25	-14.74	-11.50	-14.20	-11.31	-11.83	-11.22	-11.31	-11.44	-11.82	-11.15	-11.29	-11.74	-11.93	-14.20	-11.79	-13.82
reer*	-0.96	-0.56	-1.21	-0.71	-0.33	-0.58	-0.98	-0.72	-0.63	-0.75	-1.13	-0.57	-0.66	-1.19	-1.13	-0.37	-1.15	-0.39
d.reer*	-8.03	-7.95	-8.40	-8.41	-7.72	-8.47	-8.30	-7.57	-8.03	-7.89	-8.05	-7.80	-7.78	-7.97	-8.06	-8.26	-7.91	-8.17
dd.reer*	-10.75	-9.25	-10.37	-9.34	-9.73	-9.95	-9.94	-10.29	-9.08	-9.17	-9.85	-9.63	-9.46	-9.72	-9.70	-9.25	-9.42	-9.28
irs*	-2.65	-0.94	-1.86	-0.79	-1.60	-1.50	-0.20	-1.03	-1.35	-1.10	-0.64	-1.11	-0.61	-0.68	-0.71	-1.06	-0.82	-1.08
d.irs*	-11.78	-4.94	-16.88	-6.21	-11.97	-11.82	-5.48	-11.33	-11.62	-7.04	-10.69	-4.93	-10.95	-10.13	-10.42	-11.49	-10.33	-13.32
dd.irs*	-12.34	-19.69	-13.80	-9.61	-12.12	-11.74	-16.77	-10.82	-11.46	-10.49	-11.21	-19.42	-13.00	-10.47	-10.58	-11.02	-10.88	-11.78
irl*	0.69	1.22	0.83	0.14	1.19	0.82	0.57	1.18	0.39	0.20	0.58	0.60	1.22	0.37	0.45	0.79	0.44	0.78
d.irl*	-7.16	-6.78	-7.31	-7.65	-7.32	-7.62	-6.91	-7.80	-6.80	-7.69	-6.99	-7.10	-7.32	-6.72	-6.76	-6.65	-6.85	-7.12
dd.irl*	-13.18	-13.95	-13.28	-12.94	-14.14	-13.14	-13.47	-13.40	-14.50	-12.97	-9.00	-14.67	-8.89	-12.93	-8.86	-15.05	-12.63	-8.86

Table A3: Lag Length and Cointegrating Relations Test Results

Country	Domestics Lags	Foreign Lags	Cointegrating Relations
ARGENTINA	2	2	2
AUSTRALIA	1	1	5
BRAZIL	2	2	2
CANADA	1	2	4
CHINA	3	1	2
EURO	2	2	2
IRELAND	2	2	2
JAPAN	2	2	4
KOREA	2	1	5
MEXICO	2	2	2
NORWAY	2	1	3
NEW ZEALAND	2	1	3
SINGAPORE	2	1	1
SWEDEN	2	1	2
SWITZERLAND	1	1	3
THAILAND	2	1	3
UNITED KINGDOM	2	2	3
USA	3	1	3

Table A4: Weak Exogeneity Tests: Foreign Variables

Country	F test	F crit	gdp*	cpi*	eqty*	reer*	irs*	irl*	poil	pmat	pmetal
ARGENTINA	F(2,124)	4.7805	0.0423	0.0285	0.4966		1.1571	1.5018	2.7646	0.2359	0.3338
AUSTRALIA	F(5,120)	3.1735	0.8321	2.5122	0.8681		0.5815	2.4426	0.3768	1.6298	0.5546
BRAZIL	F(2,125)	4.7791	1.9418	1.8054	1.8582		0.0010	2.3587	3.5752	0.4421	0.5275
CANADA	F(4,121)	3.4782	3.2640	1.8877	0.5499		1.3855	1.0527	1.6035	2.7492	0.5083
CHINA	F(2,125)	4.7791	1.1823	1.7501	0.0442		4.2880	1.7719	1.7764	0.6458	1.4432
EURO	F(2,123)	4.7820	0.8897	2.4309	1.7123		2.2128	3.8104	0.3626	0.7575	1.3488
IRELAND	F(2,123)	4.7820	0.1658	1.8111	0.1275		0.8002	3.1276	0.0665	2.2397	0.7778
JAPAN	F(4,121)	3.4782	3.0410	1.4539	0.4497		2.0244	0.5729	1.0719	0.8734	1.0834
KOREA	F(5,120)	3.1735	2.5416	0.5103	2.1540		0.5889	0.9828	0.7844	0.9590	1.3205
MEXICO	F(2,125)	4.7791	1.0489	2.1211	2.6402		1.7442	1.3634	0.5019	0.1097	3.1794
NORWAY	F(3,122)	3.9463	4.6205	1.9678	2.4258		0.0465	1.0669	2.2614	1.6272	0.9316
NEW ZEALAND	F(3,122)	3.9463	3.8478	0.3843	0.0304		0.2706	0.2413	0.7694	0.6785	1.3750
SINGAPORE	F(1,125)	6.8421	0.1709	1.1511	1.9069		2.8809	1.9553	1.1769	0.2070	4.3825
SWEDEN	F(2,123)	4.7820	0.9695	1.2866	0.0875		0.1198	0.4356	0.0964	0.4192	2.0309
SWITZERLAND	F(3,122)	3.9463	0.7411	0.4014	1.3485		0.2506	0.0947	0.4936	1.4468	2.4755
THAILAND	F(3,123)	3.9449	1.8358	0.1931	0.8530		0.2129	2.2730	0.5370	0.1384	0.1061
UNITED KINGDOM	F(3,122)	3.9463	0.3342	4.4363	0.3154		0.7856	0.7741	1.0539	1.8995	1.3759
USA	F(3,126)	3.9409	0.7832	2.2013		0.3663			1.0398	1.1685	4.0050

Table A5: Parameter Stability Tests: Number and Percentage Rejections by Variable

Test	Domestic Variables						Total
Statistics	gdp	cpi	$eqty$	rer	irs	irl	(Percent)
PK_{sup}	1 (5.56%)	3 (16.67%)	0 (0%)	0 (0%)	2 (11.76%)	2 (16.67%)	8 (8.25%)
PK_{msq}	1 (5.56%)	1 (5.56%)	0 (0%)	0 (0%)	0 (0%)	1 (8.33%)	3 (3.09%)
$\mathcal{R}$	1 (5.56%)	7 (38.89%)	5 (33.33%)	3 (17.65%)	2 (11.76%)	6 (50%)	24 (24.74%)
$\mathcal{R}_{rb}$	0 (0%)	4 (22.22%)	2 (13.33%)	4 (23.53%)	3 (17.65%)	2 (16.67%)	15 (15.46%)
QLR	4 (22.22%)	13 (72.22%)	11 (73.33%)	3 (17.65%)	9 (52.94%)	10 (83.33%)	50 (51.55%)
QLR_{rb}	1 (5.56%)	3 (16.67%)	1 (6.67%)	1 (5.88%)	1 (5.88%)	1 (8.33%)	8 (8.25%)
MW	4 (22.22%)	9 (50%)	7 (46.67%)	4 (23.53%)	7 (41.18%)	7 (58.33%)	38 (39.18%)
MW_{rb}	2 (11.11%)	4 (22.22%)	3 (20%)	4 (23.53%)	3 (17.65%)	3 (25%)	19 (19.59%)
APW	3 (16.67%)	13 (72.22%)	11 (73.33%)	3 (17.65%)	9 (52.94%)	10 (83.33%)	49 (50.52%)
APW_{rb}	1 (5.56%)	3 (16.67%)	2 (13.33%)	1 (5.88%)	2 (11.76%)	2 (16.67%)	11 (11.34%)

Figure A1: Own Impulse Response of Shock Variables