

Exploring the International Linkages of the Euro Area: a Global VAR Analysis*

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Abstract

This paper presents a global model linking individual country vector error-correcting models in which the domestic variables are related to the country-specific variables as an approximate solution to a global common factor model. This global VAR is estimated for 25 countries, the euro area being treated as a single economy. This paper proposes two important extensions of previous research (see Pesaran, Schuermann and Weiner, 2004). First, it provides a theoretical framework where the GVAR is derived as an approximation to a global unobserved common factor model. Also using average pair-wise cross-section error correlations, the GVAR approach is shown to be quite effective in dealing with the common factor interdependencies and international comovements of business cycles. Second, in addition to generalised impulse response functions, we propose an identification scheme to derive structural impulse responses. We focus on identification of shocks to the US economy, particularly the monetary policy shocks, and consider the time profiles of their effects on the euro area. To this end we include the US model as the first country model and consider alternative orderings of the US variables. Further to the US monetary policy shock, we also consider oil price, US equity and US real output shocks.

Keywords: *Global VAR (GVAR), Global interdependencies, global macroeconomic modeling, impulse responses.*

JEL Classification: *C32, E17, F47*

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1 Introduction

Several developments over the past decade have drawn considerable attention to international business cycle linkages among major economies and regions. In particular the question of whether, and to what extent, the recent U.S. slowdown has influenced economic activity elsewhere in the world, especially in the euro area, has been controversial.

At the root of such discussions is the fact that the recent experience with business cycle synchronization seems to have been very different from those before. In particular, there have been remarkable differences in economic activity and business cycles across the major economies in the 1990s and several influential papers in the literature have presented evidence for a lower degree of synchronization since the 1990s.

By contrast, other strands in the literature argue that a rapidly rising degree of financial market integration has induced a closer financial and real international interdependence. Montfort, Di Mauro and Moneta (2004) show that G-7 countries share common dynamics in real economic activity, with clearly identifiable common swings across countries. Data also reveal an important effect of oil price developments in increasing business comovements. Finally, strong and increasing unilateral spill-over effects from North-America area to the European area are being found, often interpreted as being caused by the process of globalization.

In order to bridge the gap between the purely statistical analyses and the traditional modelling approaches, the present paper studies the transmission mechanisms of shocks at the world level using a global VAR. Such a framework is able to account for various transmission channels, including not only trade relationships but also financial linkages, most notably through interest rates, stock prices and exchange rates, which have proved to be particularly relevant over the recent past.¹

Following Pesaran, Schuermann and Weiner (2004), hereafter PSW, this paper presents a global model by linking 25 individual country/region vector error-correcting models in which the domestic and foreign variables are simultaneously inter-related, thus providing a general, yet practical, global modeling framework for a quantitative analysis of the relative importance of different shocks and channels of transmission mechanisms for the analysis of the comovements of outputs, inflation, interest rates, exchange rates and equity prices. To deal with the modeling issues that arise from the creation of the euro area (a single exchange rate and short term interest rate post 1999), the GVAR model presented in this paper is estimated with the euro area being treated as a single economy. This turns out to be econometrically justified and allows us to consider the impact of external shocks on the euro area as a whole without the danger of being subject to possible inconsistencies that could arise if the different economies in the euro area were modeled separately. The effects of external shocks on the euro area will be examined based on different simulations using

¹See, for example, Anderton, Di Mauro and Moneta (2004) for an overview.

Compared to the previous version of the GVAR developed by PSW, the current version also extends the geographical coverage, the estimation periods, and includes long term as well as short term interest rates, thus allowing more fully for the possible effects of changes in risk premia on output, inflation and equity prices.

In addition to these changes to the country-specific models, the paper proposes two important extensions. It provides a theoretical framework where the GVAR is derived as an approximation to a global unobserved common factor model. Also using average pair-wise cross-section error correlations, the GVAR approach is shown to be quite effective in dealing with the common factor interdependencies and international comovements of business cycles. Second, in addition to generalized impulse responses, we show how to use the GVAR model for the purpose of ‘structural’ identification. We focus on identification of shocks to the U.S. economy, particularly the monetary policy shocks, and consider the time profiles of their effects on the euro area. Further to the U.S. monetary policy shock, we also consider the effects of shocks to oil prices, U.S. equity prices and U.S. real output on the euro area and the rest of the world.

The plan of the paper is as follows: Section 2 presents the GVAR approach to model international linkages and Section 3 gives details on the version of the GVAR used in this paper. Section 4 examines the ability of the model to account for interdependencies and international comovements by computing pair-wise cross section correlations of the endogenous variables and the associated residuals. Section 5 derives generalised impulse response functions for the analysis of shocks in the U.S. on the macroeconomic variables in other countries. Section 6 provides a structural identification scheme to derive structural impulse responses of the shocks analysed in the previous section and considers the time profiles of their effects on the euro area. Section 7 checks the robustness of the GVAR results to the choice of trade weights by estimating a model using time varying weights. Section 8 discusses the issue of structural breaks in the context of the GVAR model. Section 9 offers some concluding remarks. The Appendix provides a summary of data sources used, as well as detailed results not reported in the main text.

2 Modelling International Transmissions: A GVAR Approach

One of the most striking features of the business cycles across countries are the patterns of comovement of output, inflation, interest rates and real equity prices. These comovements have become more pronounced over the past two decades due to increased economic and financial integration, with important implications for macroeconomic policy spillovers across countries. The extent of comovement of real GDP across countries has been empirically investigated by a number of authors, both by considering bivariate correlation of real GDP across countries and by decomposing the variations of real GDP into common

and country-specific shocks. Multivariate and multicountry analysis have also been undertaken in the context of G-7 economies. For example, Gregory *et al.* (1997) using Kalman filtering and dynamic factor analysis provide a decomposition of aggregate output, consumption and investment for G-7 countries into factors that are (i) common across all countries, (ii) common to the aggregates within a given country, and (iii) specific to the individual aggregates. Other similar decompositions have also been attempted by Canova and Marrinan (1998), Lumsdaine and Prasad (1999).

There are clearly many channels through which the international transmissions of business cycles can take place. In particular, they could be due to common observed global shocks (such as changes in oil prices), they could arise as a result of global unobserved factors (such as the diffusion of technological progress or regional political developments), or could be due to specific national or sectoral shocks. It is also likely that even after all such “common” factors are allowed for, there will be residual interdependencies due to policy and trade spillover effects. Therefore, a fairly detailed global framework would be needed if we are to investigate the relative importance of such diverse sources of movements in the world economy, and their impacts on the euro area. For this purpose we make use of the global vector autoregressive model (GVAR) recently developed by PSW.

To motivate the GVAR model for the analysis of the international transmission mechanisms, suppose there are $N + 1$ countries (or regions) in the global economy, indexed by $i = 0, 1, \dots, N$, and the aim is to model a number of country-specific macroeconomic variables such as real GDP, inflation, interest rates and exchange rates collected in the vector \mathbf{x}_{it} , over time, $t = 1, 2, \dots, T$, and across the $N + 1$ countries. Given the general nature of interdependencies that might exist in the world economy, it is clearly desirable that all the country-specific variables \mathbf{x}_{it} , $i = 0, 1, \dots, N$, and observed global factors (such as oil prices) are treated endogenously. The following general factor model provides a good starting point and allows us to relate the GVAR approach to the more familiar factor models used in the literature primarily for the analysis of G-7 economies.

Denote the observed global factors by the $m_d \times 1$ vector \mathbf{d}_t , and the unobserved global factors by the $m_f \times 1$ vector \mathbf{f}_t , and assume that²

$$\mathbf{x}_{it} = \boldsymbol{\delta}_{i0} + \boldsymbol{\delta}_{i1}t + \boldsymbol{\Gamma}_{id}\mathbf{d}_t + \boldsymbol{\Gamma}_{if}\mathbf{f}_t + \boldsymbol{\xi}_{it}, \text{ for } i = 0, 1, \dots, N; t = 1, 2, \dots, T, \quad (1)$$

where $\boldsymbol{\Gamma}_i = (\boldsymbol{\Gamma}_{id}, \boldsymbol{\Gamma}_{if})$ is the $k_i \times m$, matrix of factor loadings, $m = m_d + m_f$, $\boldsymbol{\xi}_{it}$ is a $k_i \times 1$ vector of country-specific factors, and $\boldsymbol{\delta}_{i0}$ and $\boldsymbol{\delta}_{i1}$ are the coefficients of the deterministics, here intercepts and linear trends. Other deterministics, such as seasonal dummies, can also be included in the model. The vector of observed global variables could include international variables such as oil or other commodity prices, world expenditure on R&D, or other indicators of global technology such as the number of international patents registered in the U.S..

²Dynamic factor models of Forni and Lippi (1997) can also be accommodated by including lagged values of \mathbf{d}_t and \mathbf{f}_t as additional factors via suitable extensions of \mathbf{d}_t and \mathbf{f}_t . For example, \mathbf{f}_t in (1) can be replaced by $\mathbf{f}_t^* = (\mathbf{f}'_t, \mathbf{f}'_{t-1}, \dots, \mathbf{f}'_{t-p_f})'$.

Unit root and cointegration properties of \mathbf{x}_{it} , $i = 0, 1, \dots, N$, can be accommodated by allowing the global factors, $\mathbf{h}_t = (\mathbf{d}'_t, \mathbf{f}'_t)'$, and/or the country-specific factors, $\boldsymbol{\xi}_{it}$, to have unit roots. More specifically, we assume that

$$\Delta \mathbf{h}_t = \Lambda(L) \boldsymbol{\eta}_t, \quad \boldsymbol{\eta}_t \sim IID(\mathbf{0}, \mathbf{I}_m), \quad (2)$$

$$\Delta \boldsymbol{\xi}_{it} = \boldsymbol{\Psi}_i(L) \mathbf{v}_{it}, \quad \mathbf{v}_{it} \sim IID(\mathbf{0}, \mathbf{I}_{k_i}), \quad (3)$$

where L is the lag operator and

$$\Lambda(L) = \sum_{\ell=0}^{\infty} \Lambda_{\ell} L^{\ell}, \quad \boldsymbol{\Psi}_i(L) = \sum_{\ell=0}^{\infty} \boldsymbol{\Psi}_{i\ell} L^{\ell}. \quad (4)$$

The coefficient matrices, Λ_{ℓ} and $\boldsymbol{\Psi}_{i\ell}$, $i = 0, 1, \dots, N$, are absolute summable, so that $Var(\Delta \mathbf{f}_t)$ and $Var(\Delta \boldsymbol{\xi}_{it})$ are bounded and positive definite, and $[\boldsymbol{\Psi}_i(L)]^{-1}$ exists. In particular we require that

$$Var(\Delta \boldsymbol{\xi}_{it}) = \sum_{\ell=0}^{\infty} \boldsymbol{\Psi}_{i\ell} \boldsymbol{\Psi}'_{i\ell} \leq \mathbf{K} < \infty, \quad (5)$$

where \mathbf{K} is a fixed bounded matrix.

First differencing (1) and using (3) we have

$$[\boldsymbol{\Psi}_i(L)]^{-1} (1-L) (\mathbf{x}_{it} - \boldsymbol{\delta}_{i0} - \boldsymbol{\delta}_{i1}t - \boldsymbol{\Gamma}_{id} \mathbf{d}_t - \boldsymbol{\Gamma}_{if} \mathbf{f}_t) = \mathbf{v}_{it}.$$

Using the approximation

$$(1-L) [\boldsymbol{\Psi}_i(L)]^{-1} \approx \sum_{\ell=0}^{p_i} \boldsymbol{\Phi}_{i\ell} L^{\ell} = \boldsymbol{\Phi}_i(L, p_i),$$

we obtain the following approximate VAR(p_i) model:

$$\boldsymbol{\Phi}_i(L, p_i) (\mathbf{x}_{it} - \boldsymbol{\delta}_{i0} - \boldsymbol{\delta}_{i1}t - \boldsymbol{\Gamma}_{id} \mathbf{d}_t - \boldsymbol{\Gamma}_{if} \mathbf{f}_t) \approx \mathbf{v}_{it}. \quad (6)$$

Without the unobserved common factors, \mathbf{f}_t , the model for the i^{th} country decouples from the rest of the country models and each country model can be estimated separately using the econometric techniques developed in Harbo *et al.* (1998) and Pesaran, Shin and Smith (2000) with \mathbf{d}_t treated as weakly exogenous. With the unobserved common factors included, the model is quite complex and its econometric analysis using Kalman filtering techniques would be quite involved unless N is very small. When N is relatively large a simple, yet effective, alternative would be to follow Pesaran (2004a) and proxy \mathbf{f}_t in terms of the cross section averages of country-specific variables, \mathbf{x}_{it} , and the observed common effects, \mathbf{d}_t . To see how this procedure could be justified in the present more complicated context, initially assume $k_i = k$ and use the same set of weights, w_j , $j = 0, 1, \dots, N$, to aggregate the country-specific relations

defined by (1) to obtain

$$\begin{aligned} \sum_{j=0}^N w_j \mathbf{x}_{jt} &= \sum_{j=0}^N w_j \boldsymbol{\delta}_{j0} + \left(\sum_{j=0}^N w_j \boldsymbol{\delta}_{j1} \right) t + \left(\sum_{j=0}^N w_j \boldsymbol{\Gamma}_{jd} \right) \mathbf{d}_t \\ &\quad + \left(\sum_{j=0}^N w_j \boldsymbol{\Gamma}_{jdf} \right) \mathbf{f}_t + \sum_{j=0}^N w_j \boldsymbol{\xi}_{jt}, \end{aligned}$$

or

$$\mathbf{x}_t^* = \boldsymbol{\delta}_0^* + \boldsymbol{\delta}_1^* t + \boldsymbol{\Gamma}_d^* \mathbf{d}_t + \boldsymbol{\Gamma}_f^* \mathbf{f}_t + \boldsymbol{\xi}_t^*. \quad (7)$$

Also, note from (3) that

$$\boldsymbol{\xi}_t^* - \boldsymbol{\xi}_{t-1}^* = \sum_{j=0}^N w_j \boldsymbol{\Psi}_j(L) \mathbf{v}_{jt}. \quad (8)$$

But using Lemma A.1 in Pesaran (2004a), it is easily seen that for each t the left hand side of (8) will converge to zero in quadratic mean as $N \rightarrow \infty$, if (5) holds, the country specific shocks, \mathbf{v}_{jt} , are independently distributed across j , and if the weights, w_j , satisfy the atomistic conditions

$$(i): w_j = O\left(\frac{1}{N}\right), \quad (ii): \sum_{i=1}^N |w_j| < K, \quad (9)$$

where K is a fixed constant. Under these conditions (for each t)

$$\boldsymbol{\xi}_t^* - \boldsymbol{\xi}_{t-1}^* \xrightarrow{q.m.} 0,$$

and hence

$$\boldsymbol{\xi}_t^* \xrightarrow{q.m.} \boldsymbol{\xi}^*,$$

where $\boldsymbol{\xi}^*$ is a time-invariant random variable. Using this result in (7) and assuming that the $k \times m_f$ average factor loading coefficient matrix, $\boldsymbol{\Gamma}_f^*$, has full column rank (with $k \geq m_f$) we obtain

$$\mathbf{f}_t \xrightarrow{q.m.} \left(\boldsymbol{\Gamma}_f^{*'} \boldsymbol{\Gamma}_f^* \right)^{-1} \boldsymbol{\Gamma}_f^* (\mathbf{x}_t^* - \boldsymbol{\delta}_0^* - \boldsymbol{\delta}_1^* t - \boldsymbol{\Gamma}_d^* \mathbf{d}_t - \boldsymbol{\xi}^*),$$

which justifies using the observable vector $\{1, t, \mathbf{d}_t, \mathbf{x}_t^*\}$ as proxies for the unobserved common factors.³ Substituting this result in (6), for N sufficiently large we have

$$\boldsymbol{\Phi}_i(L, p_i) \left(\mathbf{x}_{it} - \tilde{\boldsymbol{\delta}}_{i0} - \tilde{\boldsymbol{\delta}}_{i1} t - \tilde{\boldsymbol{\Gamma}}_{id} \mathbf{d}_t - \tilde{\boldsymbol{\Gamma}}_{if} \mathbf{x}_t^* \right) \approx \mathbf{v}_{it}, \quad (10)$$

where $\tilde{\boldsymbol{\delta}}_{i0}$, $\tilde{\boldsymbol{\delta}}_{i1}$, $\tilde{\boldsymbol{\Gamma}}_{id}$ and $\tilde{\boldsymbol{\Gamma}}_{if}$ are given in terms of $\boldsymbol{\delta}_{i0}$, $\boldsymbol{\delta}_{i1}$, $\boldsymbol{\Gamma}_{id}$, $\boldsymbol{\Gamma}_{if}$, $\boldsymbol{\delta}_0^* + \boldsymbol{\xi}^*$, $\boldsymbol{\delta}_1^*$, $\boldsymbol{\Gamma}_d^*$, and $\boldsymbol{\Gamma}_f^*$.

³In a much simpler context Pesaran (2004a) shows that it would still be valid to use $\{1, t, \mathbf{d}_t, \mathbf{x}_t^*\}$ as a proxy for \mathbf{f}_t even if the rank condition is not satisfied. It seems reasonable to believe that the same would apply here.

In practice, the number of countries, $N + 1$, may not be sufficiently large, and the individual countries not equally important in the global economy. The country-specific shocks might also be cross sectionally correlated due to spatial or contagion effects that are not totally eliminated by the common factors, \mathbf{d}_t and \mathbf{f}_t . Finally, k_i , the number of country-specific variables, need not be the same across i . For example, some markets may not exist or might not be sufficiently developed in some of the countries. Even if we focus on the same set of variables to model across countries, there will be one less exchange rate than there are countries in the global model. The GVAR framework developed in PSW addresses these considerations by using country-specific weights, w_{ij} , in construction of the proxies, namely instead of using the same \mathbf{x}_t^* in all country models they use

$$\mathbf{x}_{it}^* = \sum_{j=0}^N w_{ij} \mathbf{x}_{jt}, \text{ with } w_{ii} = 0, \quad (11)$$

in the i^{th} country model. The weights, w_{ji} , $j = 0, 1, \dots, N$ could be used to capture the importance of country j for country i^{th} economy. Geographical patterns of trade provide an obvious source of information for this purpose and could also be effective in mopping up some of the remaining spatial dependencies. The weights could also be allowed to be time-varying so long as they are pre-determined. This could be particularly important in the case of rapidly expanding emerging economies with their fast changing trade relations with the rest of the world. The use of the country-specific weights also allows a simple solution to the problem of k_i , the number of country-specific variables, being different across i . It would be sufficient to attach zero weights to the missing variable in country i , with the remaining weights being re-balanced to add up to unity.

With the above considerations in mind, the GVAR counter part of (10) may now be written as the individual country VARX $^*(p_i)$ models:

$$\Phi_i(L, p_i) \mathbf{x}_{it} = \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \Upsilon_i(L, p_i) \mathbf{d}_t + \Lambda_i(L, p_i) \mathbf{x}_{it}^* + \mathbf{u}_{it}, \quad (12)$$

for $i = 0, 1, \dots, N$, where for estimation purposes $\Phi_i(L, p_i)$, $\Upsilon_i(L, p_i)$ and $\Lambda_i(L, p_i)$ can be treated as unrestricted. These country-specific models can now be consistently estimated separately, treating \mathbf{d}_t and \mathbf{x}_{it}^* as weakly exogenous, which is compatible with a certain degree of weak dependence across \mathbf{u}_{it} . The weak exogeneity of these variables can then be tested in the context of each of the country-specific models.⁴

Once the individual country models are estimated, all the $k = \sum_{i=0}^N k_i$ endogenous variables of the global economy, collected in the $k \times 1$ vector $\mathbf{x}_t = (\mathbf{x}'_{0t}, \mathbf{x}'_{1t}, \dots, \mathbf{x}'_{Nt})'$, need to be solved simultaneously. PSW show how this can be done in the case where $p_i = 1$. In the present more general context we first

⁴For further details see PSW.

re-write (12) as⁵

$$\mathbf{A}_i(L, p_i) \mathbf{z}_{it} = \boldsymbol{\varphi}_{it}, \text{ for } i = 0, 1, 2, \dots, N \quad (13)$$

where

$$\begin{aligned} \mathbf{A}_i(L, p_i) &= [\boldsymbol{\Phi}_i(L, p_i), -\boldsymbol{\Lambda}_i(L, p_i)], \mathbf{z}_{it} = \begin{pmatrix} \mathbf{x}_{it} \\ \mathbf{x}_{it}^* \end{pmatrix}, \\ \boldsymbol{\varphi}_{it} &= \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \boldsymbol{\Upsilon}_i(L, p_i) \mathbf{d}_t + \mathbf{u}_{it}. \end{aligned}$$

Let $p = \max(p_0, p_1, \dots, p_N)$ and construct $\mathbf{A}_i(L, p)$ from $\mathbf{A}_i(L, p_i)$ by augmenting the $p - p_i$ additional terms in powers of L by zeros. Also note that

$$\mathbf{z}_{it} = \mathbf{W}_i \mathbf{x}_t, \quad i = 0, 1, 2, \dots, N, \quad (14)$$

where \mathbf{W}_i is a $(k_i + k_i^*) \times k$ matrix, defined by the country specific weights, w_{ji} .

With the above notations (13) can be written equivalently as

$$\mathbf{A}_i(L, p) \mathbf{W}_i \mathbf{x}_t = \boldsymbol{\varphi}_{it}, \quad i = 0, 1, \dots, N,$$

and then stack to yield the VAR(p) model in \mathbf{x}_t :

$$\mathbf{G}(L, p) \mathbf{x}_t = \boldsymbol{\varphi}_t, \quad (15)$$

where

$$\mathbf{G}(L, p) = \begin{pmatrix} \mathbf{A}_0(L, p) \mathbf{W}_0 \\ \mathbf{A}_1(L, p) \mathbf{W}_1 \\ \vdots \\ \mathbf{A}_N(L, p) \mathbf{W}_N \end{pmatrix}, \quad \boldsymbol{\varphi}_t = \begin{pmatrix} \boldsymbol{\varphi}_{0t} \\ \boldsymbol{\varphi}_{1t} \\ \vdots \\ \boldsymbol{\varphi}_{Nt} \end{pmatrix}. \quad (16)$$

The GVAR(p) model, (15), can now be solved recursively, and used for forecasting or generalized impulse response analysis in the usual manner. The problem of structural impulse response analysis poses special problems in the context of the GVAR model and will be dealt with in Section 6.

3 The GVAR Model (1979-2003)

The version of the GVAR model developed in this paper considers 25 separate country models plus a model for the euro area covering eight of the 11 countries that originally joined euro on January 1, 1999 (see Table 1).

The models are estimated over the period 1979(2)-2003(4). This considerably extends the 11 country/region models estimated in PSW over the shorter period 1979(2)-1999(4), most notably including the first years of EMU. The variables included in the current version of the GVAR differ also from those considered by PSW. In order to capture more fully the possible effects of changes

⁵Here we are assuming that \mathbf{d}_t is globally exogenous. But it is easy to adapt the solution approach to allow for the case where \mathbf{d}_t is included in one of the models as endogenous.

Table 1: Countries and Regions in the GVAR Model

Unites States	Euro area	Latin America
China	Germany	Brazil
Japan	France	Mexico
United Kingdom	Italy	Argentina
	Spain	Chile
Other Developed Economies	Netherlands	Peru
Canada	Belgium	
Australia	Austria	
New Zealand	Finland	
Rest of Asia	Rest of Europe	Rest of the world
Korea	Sweden	India
Indonesia	Switzerland	South Africa
Thailand	Norway	Turkey
Philippines		Saudi Arabia
Malaysia		
Singapore		

in risk premia on output and inflation we now include, where ever possible, both a short rate (ρ_{it}^S), as well as a long rate of interest (ρ_{it}^L). However, given the data limitations and problems associated with compiling comparable money supply measures we have decided against the inclusion of real money balances in the current version. Other variables included are real output (y_{it}), the rate of inflation, ($\pi_{it} = p_{it} - p_{i,t-1}$), the real exchange rate ($e_{it} - p_{it}$), and the real equity prices (q_{it}), when available. More specifically

$$\begin{aligned}
 y_{it} &= \ln(GDP_{it}/CPI_{it}), & p_{it} &= \ln(CPI_{it}), \\
 q_{it} &= \ln(EQ_{it}/CPI_{it}), & e_{it} &= \ln(E_{it}), \\
 \rho_{it}^S &= 0.25 * \ln(1 + R_{it}^S/100), & \rho_{it}^L &= 0.25 * \ln(1 + R_{it}^L/100),
 \end{aligned} \tag{17}$$

where

- GDP_{it} = Nominal Gross Domestic Product of country i during period t , in domestic currency,
- CPI_{it} = Consumer Price Index in country i at time t , equal to 1.0 in a base year (1995),
- EQ_{it} = Nominal Equity Price Index,
- E_{it} = Exchange rate of country i at time t in terms of *U.S.* dollars,
- R_{it}^S = Short rate of interest per annum, in per cent (typically a three month rate)
- R_{it}^L = Short rate of interest per annum, in per cent (typically a ten year rate)

The country-specific foreign variables, y_{it}^* , π_{it}^* , q_{it}^* , ρ_{it}^{*S} , ρ_{it}^{*L} , were constructed using trade weights. Baxter and Kouparitsas (2004) in studying the determinants of business cycle comovements conclude that bilateral trade is the most

important source of inter country business cycle linkages. Initially, we use fixed trade weights based on the average trade flows computed over the three years 1999-2001. Allowing for time-varying trade weights is straightforward and is considered in Section 7.

The time series data for the euro area was constructed by cross section weighted averages of $y_{it}, \pi_{it}, q_{it}, \rho_{it}^S, \rho_{it}^L$, over Germany, France, Italy, Spain, Netherlands, Belgium, Austria and Finland, using the average Purchasing Power Parity GDP weights, also computed over the 1999-2001 period.

With the exception of the U.S. model, all models include the country-specific foreign variables, $y_{it}^*, \pi_{it}^*, q_{it}^*, \rho_{it}^{*S}, \rho_{it}^{*L}$ and the log of oil prices (p_t^o), as weakly exogenous. In the case of the U.S. model, oil prices are included as an endogenous variable, with $e_{US,t}^* - p_{US,t}^*, y_{US,t}^*$, and $\pi_{US,t}^*$ as weakly exogenous. Given the importance of the U.S. financial variables in the global economy, the U.S.-specific foreign financial variables, $q_{US,t}^*, R_{US,t}^{*S}$ and $R_{US,t}^{*L}$, were not included in the U.S. model as they are unlikely to be weakly exogenous with respect to the U.S. domestic financial variables. The U.S.-specific foreign output and inflation variables, $y_{US,t}^*$ and $\pi_{US,t}^*$, were, however, included in the U.S. model (which were not included by PSW) in order to capture the possible second round effects of external shocks on the U.S.. Given the importance of the U.S. for the global economy, initially it was thought that the inclusion of $y_{US,t}^*$ and $\pi_{US,t}^*$ as weakly exogenous in the U.S. model might result in the violation of the weak exogeneity assumption. However, as reported below this turns out not to be the case.

In this paper, as the focus is mainly on the impact of external shocks on the euro area economy, we will from now concentrate the presentation of the results only for six countries/regions with special relevance to the euro area: United States, China, Japan, euro area, United Kingdom and rest of Europe. A more detailed set of results are available in an Appendix.

3.1 Trade Weights and Aggregation Weights

The trade shares used to construct the country-specific foreign variables (the ‘starred’ variables) are given in the 25 by 25 trade share matrix provided in the appendix. Table 2 below presents the trade shares for our eight focus economies (seven countries plus euro area itself composed of eight countries), with a ‘Rest’ category showing the trade shares with the remaining 10 countries in our sample. First considering the euro area, we can see that the U.S., the U.K. and the rest of Europe have a similar share in euro area trade (around 1/5) accounting together for almost two third of total euro area trade. Other important information that emerges from the trade matrix includes the very high share of the euro area in the trade of the U.K. and the rest of Europe (more than half of the trade relationships of these countries are with euro area countries). Hence, these countries are key in the transmission of shocks to the euro area via third market, or through second-round effects.

Table 2: Trade Weights Based on Direction of Trade Statistics

Country/ Region	U.S.	E.A.	China	Japan	U.K.	Rest of Europe			Rest*
						Sweden	Switz.	Norway	
U.S.	0	0.1553	0.0734	0.1243	0.0517	0.0082	0.0122	0.0042	0.5708
Euro area	0.2271	0	0.0565	0.0725	0.2377	0.0568	0.0897	0.0278	0.2320
China	0.2285	0.1635	0	0.2503	0.0296	0.0099	0.0066	0.0031	0.3085
Japan	0.3188	0.1319	0.1278	0	0.0317	0.0068	0.0086	0.0035	0.3711
U.K.	0.1799	0.5372	0.0198	0.0424	0	0.0272	0.0276	0.0227	0.1431
Sweden	0.1036	0.5139	0.0243	0.0352	0.1143	0	0.0175	0.1015	0.0896
Switzerland	0.1133	0.6699	0.0151	0.0390	0.0656	0.0148	0	0.0036	0.0788
Norway	0.0903	0.4491	0.0197	0.0300	0.1809	0.1322	0.0084	0	0.0895

Note: Trade weights are computed as shares of exports and imports displayed in rows by region such that a row, but not a column, sums to one.

*"Rest" gathers the remaining countries. The complete trade matrix used in the GVAR model is given in the appendix

Source: Direction of Trade Statistics, 1999-2001, IMF.

Although we estimate models at a country level (the euro area being considered here as a single economy), we also wish to derive regional responses to shocks. Hence, for the rest of Europe (and also for rest of Asia, Latin America, Other Developed Countries and rest of the world), we will aggregate impulse response functions by using weights based on the PPP valuation of country GDPs, which are thought to be more reliable than weights based on U.S. dollar GDPs.

3.2 Unit Root Tests

Although the GVAR methodology can be applied to stationary and/or integrated variables, here we follow PSW and assume that the variables included in the country-specific models are integrated of order one (or $I(1)$). This allows us to distinguish between short run and long run relations and interpret the long run relations as cointegrating. Therefore, we begin by examining the integration properties of the individual series under consideration. In view of the widely accepted poor power performance of traditional Dickey-Fuller (DF) tests, we report unit root t-statistics based on weighted symmetric estimation of ADF type regressions introduced by Park and Fuller (1995). These tests, henceforth *WS*, exploit the time reversibility of stationary autoregressive processes in order to increase their power performance. Leybourne *et al.* (2004) and Pantula *et al.* (1995) provide evidence of superior performance of the *WS* test statistic compared to the standard ADF test or the GLS-ADF test proposed by Elliot *et al.* (1996). The lag length employed in the *WS* unit root tests is selected by the Akaike Information Criterion (AIC) based on standard ADF regressions. Table 3 presents *WS* statistics for the level, first difference and the second differences of all the country-specific domestic variables in the GVAR model, namely the

domestic variables plus the oil prices, whilst Table 4 summarizes the test results for the country-specific foreign variables.⁶

Real output, interest rates (short and long), exchange rates and real equity prices (domestic and foreign) are $I(1)$ across the focus countries, with two notable exceptions. First, real output in the UK appears borderline $I(0)/I(1)$ according to the WS statistics, although ADF tests indicate that UK real output is $I(1)$. Second, e^* in the U.S. model is an $I(2)$ variable. As in PSW, we deal with this problem by including the real exchange rate $(e - p)$ instead of the nominal exchange rate variable, e , in the different country-specific models. Unit root tests applied to $(e - p)$ and $(e^* - p^*)$ indicate that these variables are $I(1)$ in all cases. Finally, consumer price indices turn out to be $I(2)$, so that inflation (Δp and Δp^*) appears to be $I(1)$ across all countries. The test results also generally support the unit root hypothesis in the case of the variables for the remaining countries except for $(e - p)$ and $(e^* - p^*)$ for Canada and $(e^* - p^*)$ for Mexico. See Appendix.

⁶Details of the computation of the WS statistics can be obtained from the authors on request.

Table 3: Unit Root Test Statistics for Domestic Variables

Domestic Variables	Country/Region ^a							
	U.S.	E.A.	China	Japan	U.K.	Sweden	Switz.	Norway
y	-2.76	-2.44	-3.75	-1.35	-3.64	-2.83	-2.36	-2.60
Δy	-6.93	-4.60	-3.34	-3.46	-3.21	-14.51	-6.77	-5.43
$\Delta^2 y$	-6.99	-8.12	-9.90	-14.30	-11.98	-8.90	-7.32	-8.02
p	-.11	-2.01	-3.61	-0.60	-.39	-.77	-1.48	-1.51
Δp	-.07	.29	-3.16	-0.54	-.61	-1.18	-1.81	-1.38
$\Delta^2 p$	-13.91	-11.15	-4.90	-13.45	-6.44	-12.20	-12.77	-12.98
e	-	-2.45	-0.88	-2.43	-2.40	-2.80	-2.73	-2.10
Δe	-	-7.17	-9.08	-4.25	-7.96	-3.87	-7.92	-7.60
$\Delta^2 e$	-	-8.90	-8.46	-9.09	-8.38	-7.01	-7.70	-7.26
$e - p$	-	-2.09	-2.22	-2.09	-2.61	-2.58	-2.18	-2.20
$\Delta(e - p)$	-	-7.48	-4.02	-8.11	-7.90	-3.89	-7.95	-7.70
$\Delta^2(e - p)$	-	-8.96	-13.00	-9.60	-8.40	-12.03	-12.47	-7.11
ρ^S	-1.17	-1.26	-1.20	-1.61	-1.76	-1.95	-1.77	-1.77
$\Delta \rho^S$	-3.63	-5.51	-7.68	-5.65	-10.95	-10.16	-5.14	-10.73
$\Delta^2 \rho^S$	-10.40	-9.34	-7.17	-7.79	-7.60	-8.40	-7.71	-7.64
ρ^L	-3.84	-2.71	-	-1.95	-3.59	-3.18	-2.41	-.98
$\Delta \rho^L$	-7.75	-4.58	-	-8.87	-7.74	-6.34	-6.22	-6.73
$\Delta^2 \rho^L$	-7.05	-7.59	-	-9.88	-8.11	-7.07	-7.51	-7.28
q	-2.07	-3.05	-	-1.46	-1.47	-2.50	-1.23	-3.06
Δq	-7.52	-4.26	-	-6.79	-8.46	-7.14	-9.39	-5.53
$\Delta^2 q$	-8.68	-12.43	-	-6.83	-7.46	-11.15	-7.96	-7.10
p^0	-2.86	-	-	-	-	-	-	-
Δp^0	-5.61	-	-	-	-	-	-	-
$\Delta^2 p^0$	-8.00	-	-	-	-	-	-	-

Note: The WS statistics are based on univariate AR(p) specifications in the level of the variables with $p \leq 5$, and the statistics for the level, first differences and second differences of the variables are all computed based on the same sample period, namely, 1980Q2-2003Q4. The WS statistics for all level variables are based on regressions including a linear trend, except for the interest rate variables. The 95% critical value of the WS test for a regression with a linear trend is -3.24, and for a regression with an intercept only is -2.55.

^a The unit root test statistics for all the countries are given in the Appendix

Table 4: Unit Root Test Statistics for Foreign Variables

Foreign Variables	Country/Region ^a							
	U.S.	E.A.	China	Japan	U.K.	Sweden	Switz.	Norway
y^*	-3.84	-2.72	-1.67	-2.45	-2.50	-2.62	-2.45	-2.96
Δy^*	-5.20	-4.75	-5.84	-5.66	-4.86	-4.90	-4.65	-5.43
$\Delta^2 y^*$	-5.84	-6.72	-13.28	-6.60	-6.51	-6.33	-6.11	-6.75
p^*	-1.02	-.26	-.63	-0.79	-.77	-.92	-.81	-1.11
Δp^*	-1.25	-1.68	-.56	-0.94	-.22	-.09	-.53	-.46
$\Delta^2 p^*$	-11.75	-5.26	-11.47	-4.35	-13.60	-5.87	-13.00	-5.56
e^*	-1.18	-.87	-2.17	-1.26	-2.50	-1.86	-2.50	-2.53
Δe^*	-2.38	-6.86	-7.28	-7.20	-7.21	-7.32	-7.21	-7.21
$\Delta^2 e^*$	-10.71	-7.16	-9.33	-7.77	-9.07	-9.09	-9.07	-8.87
$e^* - p^*$	-2.40	-1.99	-1.62	-1.93	-1.95	-2.05	-2.03	-2.02
$\Delta(e^* - p^*)$	-8.26	-7.34	-7.55	-6.93	-7.47	-7.55	-7.49	-7.44
$\Delta^2(e^* - p^*)$	-10.90	-7.46	-9.46	-9.89	-9.08	-9.04	-9.07	-8.83
ρ^{*S}	-	-1.38	-1.26	-1.01	-.77	-.95	-.98	-.98
$\Delta \rho^{*S}$	-	-9.63	-4.74	-5.34	-7.46	-8.17	-7.91	-9.81
$\Delta^2 \rho^{*S}$	-	-9.60	-8.82	-8.62	-8.81	-9.16	-9.22	-8.45
ρ^{*L}	-	-3.88	-2.80	-3.17	-2.24	-2.26	-2.30	-2.46
$\Delta \rho^{*L}$	-	-5.50	-4.91	-5.56	-5.05	-5.06	-4.92	-5.25
$\Delta^2 \rho^{*L}$	-	-7.82	-7.33	-7.58	-7.13	-7.47	-7.09	-7.58
q^*	-	-2.32	-2.11	-2.38	-2.94	-2.80	-2.86	-2.71
Δq^*	-	-6.98	-6.54	-7.29	-4.47	-4.53	-4.39	-7.18
$\Delta^2 q^*$	-	-11.18	-10.91	-11.00	-12.11	-12.31	-12.25	-11.94
p^0	-	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86
Δp^0	-	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61
$\Delta^2 p^0$	-	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00

Note: The WS statistics are based on univariate AR(p) specifications in the level of the variables with $p \leq 5$, and the statistics for the level, first differences and second differences of the variables are all computed based on the same sample period, namely, 1980Q2-2003Q4. The WS statistics for all level variables are based on regressions including a linear trend, except for the interest rate variables. The 95% critical value of the WS test for a regression with a linear trend is -3.24, and for a regression with an intercept only is -2.55.

^a The unit root test statistics for all the countries are given in the Appendix.

3.3 Specification and Estimation of the Country-Specific Models

Based on the unit root test results and the available variables we specify different country-specific models as follows. First, for the euro area, Japan, the UK, and countries belonging to the rest of Europe, we include real output (y), inflation rate (Δp), short-term interest rate (ρ^S), long-term interest rate (ρ^L), real equity prices (q) and real exchange rate ($e - p$) as endogenous variables and foreign real output (y^*), foreign inflation (Δp^*), foreign real equity prices (q^*), foreign interest rates (short - ρ^{*S} - and long - ρ^{*L} -) and oil prices (p^o) as weakly exogenous variables. In the case of China, owing to data constraints, real equity prices and long-term interest rate are excluded from the set of endogenous variables. The U.S. model contains y , Δp , ρ^S , ρ^L , q and oil prices (p^o), as the endogenous variables. The U.S. dollar exchange rate is determined outside the U.S. model. As in PSW the only exchange rate included in the U.S. model is the foreign real exchange rate variable, ($e_{US}^* - p_{US}^*$) which is treated as weakly exogenous. The inclusion of oil prices in the U.S. model as endogenous, allows the evolution of the global macroeconomic variables to influence oil prices, a feature which was absent from the PSW version which treated oil prices as weakly exogenous in all country-specific models. Furthermore, unlike the PSW version, the present specification includes U.S.-specific foreign real output (y_{US}^*) and foreign inflation (Δp_{US}^*) as weakly exogenous variables. This allows for the U.S. model to be more fully integrated in the world economy and hence to take a more satisfactory account of second round effects in the global economic system as a whole. It is, of course, important that the weak exogeneity of these variables in the U.S. model are tested, and this is done below.

Once the variables to be included in the different country models are specified, the corresponding cointegrating VAR models are estimated and the rank of their cointegrating space determined. Initially we select the order of the individual country VARX^{*}(p_i) models given in (12). In the empirical analysis that follows we entertain the case where the lag length of the VARX^{*} model, $p_i < p_{\max i}$, is the same for both the domestic and foreign variables. However, this is not a requirement of the GVAR modelling methodology and can be easily relaxed. Due to data limitations we do not consider $p_{\max i}$ to be greater than two. The model selection criterion used is the AIC, which is known to be less conservative than the Schwartz Bayesian Criterion (SBC). Preference for the former is based on the argument that over-estimating the order of the VARX^{*} can result in efficiency loss, which is less serious than underestimating the lag order that could lead to inconsistent estimates. We then proceed with the cointegration analysis, where the country specific models are estimated subject to reduced rank restrictions. To this end, the error-correction forms of the individual country equations given by (12) are derived.

The rank of the cointegrating space for each country/region was computed using Johansen's trace and maximal eigenvalue statistics as set out in Pesaran, Shin and Smith (2000) for models with weakly exogenous $I(1)$ regressors, in the case where unrestricted constants and restricted trend coefficients are included

in the individual country error correction models.

Table 5 presents the cointegration rank statistics for the euro area, Japan, the UK and the rest of Europe. Tables 6 and 7 present these statistics for China and the U.S., respectively. The order of the VARX* models as well as the number of cointegration relationships are presented in Table 8. Among the countries of interest, the VARX* models have an order of 2 except for Switzerland whose lag order is 1. As regards the number of cointegrating relationships, we find 5 for Japan, 3 for U.K. and the rest of Europe, 2 for the euro area and the U.S. and 1 for China. The cointegration results are based on the trace statistic, which is known to yield better small sample power results compared to the maximal eigenvalue statistic.

Table 5: Cointegration Rank Statistics for the euro area, Japan, the UK and the rest of Europe

H_0	H_1	Country/Region ^a						Critical Value 95%
		E.A.	Japan	U.K.	Sweden	Switz.	Norway	
Maximum eigenvalue statistics								
$r = 0$	$r = 1$	77.82	73.65	97.68	83.54	97.35	104.75	63.52
$r \leq 1$	$r = 2$	55.97	55.78	69.90	75.61	76.39	66.26	57.13
$r \leq 2$	$r = 3$	38.37	46.50	49.51	54.07	56.46	50.44	50.64
$r \leq 3$	$r = 4$	31.74	40.08	35.33	36.87	33.85	34.58	43.94
$r \leq 4$	$r = 5$	24.06	39.47	26.02	27.97	20.19	28.27	36.84
$r \leq 5$	$r = 6$	15.80	19.46	14.43	19.58	16.77	18.92	28.81
Trace statistics								
$r = 0$	$r > 1$	243.76	273.61	292.87	297.64	301.01	303.22	197.70
$r < 1$	$r \geq 2$	165.94	199.96	195.19	214.10	203.66	198.48	156.44
$r \leq 2$	$r \geq 3$	109.97	144.18	125.29	138.49	127.27	132.22	119.03
$r \leq 3$	$r \geq 4$	71.60	97.67	75.79	84.42	70.81	81.78	85.44
$r \leq 4$	$r \geq 5$	39.85	57.60	40.45	47.55	36.96	47.19	55.50
$r \leq 5$	$r \geq 6$	15.80	18.13	14.43	19.58	16.77	18.92	28.81

^a Test results for the remaining countries are provided in an Appendix.

Table 6: Cointegration Rank Statistics for China

H_0	H_1	China	Critical Value 95%
Maximum Eigenvalue Statistics			
$r = 0$	$r = 1$	99.10	50.64
$r \leq 1$	$r = 2$	30.72	43.94
$r \leq 2$	$r = 3$	23.57	36.84
$r \leq 3$	$r = 4$	18.57	28.81
Trace Statistics			
$r = 0$	$r > 1$	171.97	119.03
$r < 1$	$r \geq 2$	72.86	85.44
$r \leq 2$	$r \geq 3$	42.14	55.50
$r \leq 3$	$r \geq 4$	18.57	28.81

Table 7: Cointegration Rank Statistics for the US

H_0	H_1	U.S.	Critical Value 95%
Maximum Eigenvalue Statistics			
$r = 0$	$r = 1$	92.49	54.24
$r \leq 1$	$r = 2$	56.87	47.99
$r \leq 2$	$r = 3$	32.77	41.66
$r \leq 3$	$r = 4$	20.37	35.19
$r \leq 4$	$r = 5$	16.18	28.43
$r \leq 5$	$r = 6$	6.76	20.98
Trace Statistics			
$r = 0$	$r > 1$	225.45	158.01
$r < 1$	$r \geq 2$	132.96	122.96
$r \leq 2$	$r \geq 3$	76.08	91.81
$r \leq 3$	$r \geq 4$	43.31	64.54
$r \leq 4$	$r \geq 5$	22.94	41.03
$r \leq 5$	$r \geq 6$	6.76	20.98

Table 8: VAR Order and Number of Cointegration Relationships in the Country-Specific Models

Country (selection) ^a	VAR order	# Cointegrating Relationships
Unites States	2	2
Euro area	2	2
China	2	1
Japan	2	5
United Kingdom	2	3
Sweden	2	3
Switzerland	1	3
Norway	2	3

^a Test results for the remaining countries are provided in an Appendix.

3.4 Testing Weak Exogeneity

The final step in our estimation procedure concerns the test of the weakly exogeneity of the country-specific foreign variables (the “starred” variables) and the oil prices. Weak exogeneity is tested along the lines described in Johansen (1992) and Harbo et al (1998). This involves a test of the joint significance of the estimated error correction terms in auxiliary equations for the country-specific foreign variables, \mathbf{x}_{it}^* . In particular, for each l^{th} element of \mathbf{x}_{it}^* the following regression is carried out

$$\Delta x_{it,l}^* = \mu_{il} + \sum_{j=1}^{r_i} \gamma_{ij,l} ECM_{i,t-1}^j + \sum_{k=1}^{s_i} \varphi_{ik,l} \Delta \mathbf{z}_{i,t-k} + \eta_{it,l}$$

where $ECM_{i,t-1}^j$, $j = 1, 2, \dots, r_i$ are the estimated error correction terms corresponding to the r_i cointegrating relations found for the i^{th} country model and $\Delta \mathbf{z}_{i,t-k} = (\Delta \mathbf{x}_{i,t-k}'^*, \Delta \mathbf{x}_{i,t-k}', \Delta(e_{i,t-k}^* - p_{i,t-k}^*))'$. Note that in the case of the U.S. the term $\Delta(e_{i,t-k}^* - p_{i,t-k}^*)$ is implicitly included in $\Delta \mathbf{x}_{i,t-k}'^*$. The test for weak exogeneity is an F test of the joint hypothesis that $\gamma_{ij,l} = 0$, $j = 1, 2, \dots, r_i$ in the above regression. The lag order s_i , need not be the same as the order of the underlying country-specific VARX* models. Given the data limitations we carried out two sets of experiments, one set using the lag order selected for the underlying VARX* model, and in another set of experiments we set $s_i = 2$ for all countries. The results turn out to be very similar, except for Japan.

Table 9 presents the F-statistics associated with the weak exogeneity tests. For the set of focus countries, as can be seen from this table, the weak exogeneity assumptions are not rejected with the exception of foreign inflation in Norway, which indicates rejection at the 5% significance level.⁷ This does not seem to us to be too serious a violation and could have arisen due to insufficient dynamics. We would have been much more concerned if the weak exogeneity assumptions were rejected in the case of the U.S. or the euro area models, for example. But as can be seen from Table 9, the weak exogeneity of foreign variables and oil prices are not rejected in the euro area model. Aggregation of the euro area countries in a single model could have violated the weak exogeneity assumptions that underlie GVAR modeling. However, the tests suggest that the foreign euro area-specific variables can be considered as weakly exogenous. The same applies to the foreign variables $(y_{US}^*, \Delta p^*, e_{US}^* - p_{US}^*)$ included in the U.S. model. As expected foreign real equity prices and foreign interest rates (both short and long term) cannot be considered as weakly exogenous and have thus not been included in the U.S. model.

3.5 Contemporaneous Effects of Foreign Variables on Their Domestic Counterparts

Table 10 presents the contemporaneous effects of foreign variables on their domestic counterparts. These values can be interpreted as impact elasticities be-

⁷See Appendix for the exogeneity tests for the remaining countries.

Table 9: F Statistics for Testing the Weak Exogeneity of the Country-specific Foreign Variables and Oil Prices

Country ^a		Foreign Variables						
		y^*	Δp^*	q^*	ρ^{*S}	ρ^{*L}	p^o	$e^* - p^*$
Unites States	$F(2, 75)$	.16	1.22	-	-	-	-	1.90
Euro area	$F(2, 67)$	.09	.01	2.35	.22	2.07	2.31	-
China	$F(1, 72)$	.21	1.70	3.86	.09	1.14	.32	-
Japan	$F(5, 64)$	.63	.86	.67	1.48	1.32	1.29	-
United Kingdom	$F(3, 66)$	1.88	.24	.39	1.11	.83	1.04	-
Sweden	$F(3, 66)$	2.47	1.49	.08	.40	.30	.51	-
Switzerland	$F(3, 80)$	1.56	.71	.67	.95	.41	1.29	-
Norway	$F(3, 66)$	.57	2.81*	.84	.59	.54	.82	-

^aTest results for the remaining countries are provided in an Appendix.

tween domestic and foreign variables. Most of these elasticities are significant and have a positive sign, as expected.

These elasticities are very informative as regards the international linkages between the domestic and foreign variables. Focusing on the euro area, we can see that a 1% change in foreign real output in a given quarter leads to an increase of 0.5% in euro area real output within the same quarter. Similar foreign output elasticities are obtained across the different regions, though the effect is slightly weaker for the U.S.. The relatively large and statistically significant elasticity estimate obtained in the case of the euro area largely reflects the high degree of trade openness of the euro area economy.

We can also observe a high elasticity between the spreads, $(\rho^L - \rho^S)$ and $(\rho^{*L} - \rho^{*S})$, implying relatively strong comovements between euro area and foreign bond markets. More importantly, the contemporaneous elasticity of real equity prices is significant and slightly above one. Hence, the euro area stock markets would seem to overreact to foreign stock price changes, although the extent of over-reaction is not very large and is statistically significant only marginally. Similar results are also obtained for Sweden and Norway. Contemporaneous financial linkages are likely to be very strong amongst the European economies through the equity and the bond market channels.

In contrast, we find rather low elasticities for inflation. For the euro area the foreign inflation elasticity is 0.12 and is not statistically significant, suggesting that in the short run the euro area prices are not much affected by changes in foreign prices. The same is also true for the U.S., and to lesser extent, for the U.K. inflation rates. For the remaining focus countries foreign inflation effects are much larger and are statistically significant.

Another interesting feature of the results is the very weak linkages that seem to exist across short-term interest rates (Sweden being an exception) and the high, significant relationships across long-term rates. This clearly shows a

much stronger relation between bond markets than between monetary policy reactions.

Table 10: Contemporaneous Effects of Foreign Variables on their Domestic Counterparts

Country ^a	Domestic Variables				
	y	Δp	q	ρ^S	ρ^L
Unites States	.34* (.10)	.05 (.06)	-	-	-
Euro area	.49* (.11)	.12 (.08)	1.16* (.08)	.09* (.02)	.63* (.08)
China	.09 (.16)	1.47* (.71)	-	0.14* (.07)	-
Japan	.32 (.19)	.53* (.12)	.58* (.14)	-.04 (.05)	.39* (.10)
United Kingdom	.44* (.14)	.47 (.26)	.87* (.07)	.24 (.16)	.75* (.14)
Sweden	.30 (.31)	1.30* (.24)	1.26* (.12)	1.20* (.30)	.88* (.14)
Switzerland	.47* (.12)	.51* (.14)	.70* (.13)	.14* (.07)	.41* (.07)
Norway	1.20* (.38)	1.08* (.20)	.99* (.13)	.20* (.11)	.56* (.15)

Note: * denotes statistical significance at the 5% level or less. Standard errors are in parentheses.

^a Test results for the remaining countries are provided in an Appendix.

4 Pair-wise Cross Section Correlations: Variables and Residuals

One of the key assumptions of the GVAR modeling approach is that the “idiosyncratic” shocks of the individual country models should be cross sectionally “weakly correlated”, so that $Cov(\mathbf{x}_{it}^*, u_{it}) \rightarrow 0$, as $N \rightarrow \infty$ and as a result the weak exogeneity of the foreign variables is ensured. Direct tests of weak exogeneity assumptions discussed above indirectly support the view that the idiosyncratic shocks could only be weakly correlated. In this section we provide direct evidence on the extent to which this is likely to be true. The basic idea is similar to the cross section dependence test proposed in Pesaran (2004b). By conditioning the country-specific models on weakly exogenous foreign variables, viewed as proxies for the “common” global factors, it is reasonable to expect that the degree of correlation of the remaining shocks across countries/regions will be modest. These residual interdependencies, as mentioned in the introduction, could reflect policy and trade spillover effects.

As a simple diagnostic of the ability of the model to account for interdependencies and international comovements, we have computed average pair-wise

cross-section correlations for the levels and first differences of the endogenous variables of the model, as well as those of the associated residuals over the estimation period, 1979-2003. The results are summarized in Tables 11 to 16, for real outputs, inflation, real equity prices, real exchange rate, short-term interest rate and the term premia, respectively.

Table 11: Average Pair-wise Cross Section Correlations of Real Output and Associated Model's Residuals

Country	Levels	1st Difference	Residuals
United States	0.96	0.05	-0.04
Euro area	0.96	0.14	-0.01
China	0.96	0.02	-0.02
Japan	0.92	0.03	-0.08
United Kingdom	0.95	0.09	-0.00
Sweden	0.96	0.07	0.02
Switzerland	0.93	0.13	0.02
Norway	0.96	0.08	0.01

Table 12: Average Pair-wise Cross Section Correlations of Inflation and Associated Model's Residuals

Country	Levels	1st Difference	Residuals
United States	0.41	0.12	0.02
Euro area	0.40	0.11	-0.01
China	-0.00	-0.02	-0.05
Japan	0.31	0.01	0.01
United Kingdom	0.37	0.06	0.01
Sweden	0.37	0.06	0.00
Switzerland	0.31	0.07	0.04
Norway	0.31	0.07	0.04

Table 13: Average Pair-wise Cross Section Correlations of Real Equity Prices and Associated Model's Residuals

Country	Levels	1st Difference	Residuals
United States	0.59	0.39	-0.02
Euro area	0.58	0.42	-0.08
Japan	0.37	0.31	-0.08
United Kingdom	0.61	0.40	-0.03
Sweden	0.57	0.38	-0.04
Switzerland	0.54	0.26	-0.05
Norway	0.61	0.36	0.01

Table 14: Average Pair-wise Cross Section Correlations of Real Exchange Rates and Associated Model's Residuals

Country	Levels	1st Difference	Residuals
Euro area	0.62	0.31	0.27
China	-0.22	0.06	0.02
Japan	0.60	0.22	0.17
United Kingdom	0.62	0.28	0.18
Sweden	0.59	0.28	0.21
Switzerland	0.63	0.27	0.26
Norway	0.62	0.31	0.26

Table 15: Average Pair-wise Cross Section Correlations of Short Term Interest Rates and Associated Model's Residuals

Country	Levels	1st Difference	Residuals
United States	0.38	0.10	0.02
Euro area	0.49	0.16	0.04
China	0.32	0.03	-0.05
Japan	0.47	0.07	-0.00
United Kingdom	0.51	0.12	0.01
Sweden	0.46	0.04	0.00
Switzerland	0.33	0.09	-0.02
Norway	0.40	0.03	-0.00

Table 16: Average Pair-wise Cross Section Correlations of Term Premia and Associated Model's Residuals

Country	Levels	1st Difference	Residuals
United States	0.76	0.40	-0.03
Euro area	0.78	0.45	-0.05
Japan	0.76	0.29	-0.05
United Kingdom	0.78	0.39	-0.02
Sweden	0.80	0.37	0.07
Switzerland	0.59	0.38	0.02
Norway	0.72	0.28	0.02

The average cross section correlations are generally high for the level of the endogenous variables and fall as first differences of these variables are considered. The results vary widely across variables and less so across countries, with inflation and real exchange rate for China being the exceptions. Output levels, sharing common trends, show the highest degree of cross section correlations of around 92%-96%. This is followed by term premia (72%-80%) real equity prices (37%-61%), and short-term interest rates (32%-51%). The effect of first differencing on cross section correlations differ widely over variables as well as countries, and is most pronounced in the case of the output series. Average cross section correlations of output changes, Δy_{it} , range between 2% for China to 14% for the euro area, as compared to cross section correlations of output levels of 96% for both of these economies. Similar outcomes are also observed in the case of inflation and short-term interest rates. By comparison, first differencing of equity prices and term premia have only limited effects on cross section correlations. For example, the average cross section correlations of equity prices fall from 37%-61% to 26%-42% as one moves from levels of equity prices to their first differences. Overall, there is significant evidence of cross country correlations for the variables in the GVAR model, although the extent of this correlation depends on the variable, whether it is transformed to

stationarity by first differencing, and the country.

Turning to the cross section correlation of the residuals, it is quite striking that except for real exchange rates these correlations are very small and do not depend on the choice of the variable or country. This is particularly apparent in the case of the equity and bond markets where the cross section correlation of the residuals ranges between -8% and +7%, as compared to the values in the range 37% and 80% (or 26% and 45%) if cross section correlations of the levels (or first differences) are considered. The model has clearly been successful in capturing the common effects driving bond and equity markets. The real exchange rate variable presents an important exception which requires further consideration.

Overall, the cross section correlation results show the importance of country-specific variables in dealing with often significant dependencies that exist across macroeconomic variables. Although, these results do not constitute a formal statistical test of the importance of the foreign variables in the GVAR model, they do provide an important indication of their usefulness in modeling global interdependencies. The results also show that once country-specific models are formulated conditional on foreign variables, there remains only a modest degree of correlations across the shocks from different regions.

5 Generalized Impulse Response Functions

To study the dynamic properties of the global model and to assess the time profile of the effects of shocks to foreign variables on the euro area economy, we investigate the implications of four different external shocks:

- A one standard error positive shock to oil prices
- A one standard error negative shock to U.S. real equity prices
- A one standard error negative shock to U.S. real GDP
- A one standard error positive shock to U.S. interest rates

In this section we make use of the Generalized Impulse Response Function (GIRF), proposed in Koop, Pesaran and Potter (1996) for non-linear models and discussed in further details in Pesaran and Shin (1998) for vector error correcting models. The GIRF is an alternative to the Orthogonalized Impulse Responses (OIR) of Sims (1980). The OIR approach requires the impulse responses to be computed with respect to a set of orthogonalized shocks, whilst the GIR approach considers shocks to individual errors and integrates out the effects of the other shocks using the observed distribution of all the shocks without any orthogonalization. Unlike the OIR, the GIRF is invariant to the ordering of the variables and the countries in the GVAR model, which is clearly an important consideration. Even if a suitable ordering of the variables in a given country model can be arrived at from economic theory or general *a priori* reasoning, it is not clear how to order countries in the application of the OIR to the GVAR model.

In the absence of strong a priori beliefs on ordering of the variables and/or countries in the GAVR model, the GIRFs provide useful information with respect to changes in oil prices, equity prices and even interest rates. Although, the approach is silent as to the reasons behind the changes, the GIRFs can be quite informative about the dynamics of the transmission of shocks from the rest of the world to the euro area.

In the discussion of the results, we focus only on the first two years following the shock. This seems a reasonable time horizon over which the model presents credible results. We have, however, included figures (see Appendix) of the GIRFs over a longer period. The figures display results over 40 quarters and are intended as visual aids for the analysis of model's convergence properties. The figures clearly show that the model is stable (the endogenous variables return gradually to their long run solution in a reasonable amount of time). This is also supported by the eigenvalues of the GVAR model. The model contains 134 endogenous variables and the rank of the global cointegrating matrix is at most 65. Hence, the global system should have at least 69 eigenvalues (i.e. $134 - 65$), that fall on the unit circle. The GVAR satisfies these properties and indeed has 65 eigenvalues equal to unity, with the remaining 199 eigenvalues having moduli all less than unity.⁸

5.1 Shock to Oil Prices

Table 17 presents the GIRFs of a positive one standard error shock to oil prices on the regions of interest over the first two years. A one standard error positive shock results in a 13-14% increase per quarter in the price of oil.

On impact the oil price shock has diverse effects on real output across countries. In the U.S., the U.K., the euro area and the rest of Europe, the increase in oil prices has a negative impact on real output. This negative effect persists in the U.S., the euro area and the U.K. after 2 years. The U.S. seems to be the most affected economy. This result is consistent with other studies showing the higher dependence of the U.S. economy to oil than the other industrialized economies. The effect in the U.K. is dampened by the fact that the economy is also an oil producer.

The impact is instead positive and significant for Japan and China. For the former, this is a result entirely at odds with general belief based on standard indicators of oil dependency of the Japanese economy. The result for China could be due to her sustained (so far) high levels of output growth over the past decade that has coincided with episodes of high and low oil prices. The high output elasticity of energy demand in China could also be behind the seemingly

⁸Of these 199 eigenvalues, 156 (78 pairs) are complex, implying the cyclical properties of the impulse response functions. The eigenvalues with the largest complex part are $.017534 \pm 0.716540i$, $.088455 \pm 0.687295i$ and $.028015 \pm 0.656728i$, where $i = \sqrt{-1}$. After the unit roots, the three largest eigenvalues (in moduli) are .9358, .9015 and .8948, implying a reasonable rate of convergence of the model after a shock to its long-run equilibrium. Given the unit eigenvalues of the system, some shocks will have permanent effects on the levels of the endogenous variables.

perverse results which we have obtained. Further empirical investigation is clearly needed.

Regarding inflationary impacts, the oil price shock is less ambiguous. All countries, except China, exhibit an increase in inflation by more than 0.1 percent. Again, the U.S. response is the largest, which is consistent with what we observe on the real side, which is in line with a rise in short-term interest rates, triggered in turn by increased inflationary pressures.

As regards financial variables, the increase in oil prices coincides with downward movements in equity prices and increases in the interest rate spreads. The increase in long-term interest rates show that the bond markets tend to react more to inflation expectations rather than to the growth prospects. Bond and equity market reactions are consistent with each other and are common to all regions.

Interestingly, the real exchange rate reaction is mixed across countries/regions. The yen depreciates rather substantially, as compared to the other currencies. This result may explain the differences already observed regarding the effect of the oil price shock on real output; the depreciation of the yen implying positive effects on competitiveness and hence on exports. This positive effect could then more than compensate the negative impact of oil price increases on economic activity.

5.2 Shock to U.S. Equity Prices

The point estimates of the GIRFs for a one standard error negative shock to U.S. equity prices over a two-year horizon are given in Table 18. This shock is equivalent to a fall of around 6-7% in U.S. real equity prices per quarter. In the U.S., the equity price shock is accompanied by a decline in real GDP by 0.1% on impact, by 0.4% on average over the first year and by 0.6% on average over the second year.

The transmission of the shocks to the other equity markets is rather quick and significant. On impact, equity prices fall by 2.6% in Japan, 5.5% in the euro area, 4.8% in the U.K. and 4.8% in the rest of Europe. Over time, the decrease in equity prices converges to the U.S. responses and is even stronger in the case of the euro area and the rest of Europe. This shows that markets have tended to overreact to shocks, equity prices in the European markets overshooting the U.S. responses, partly reflecting the higher volatility of the European equity markets as compared to the volatility of the S&P 500 used as the market index for the U.S..

Like in the U.S., real output in euro area is negatively affected by the adverse equity shock, although to a lesser extent. Inflation tends to decrease although the magnitude of the reaction remains very limited. Short-term interest rates and spreads also marginally decrease. The impact on the former is stronger in the U.S. and the U.K. than in the euro area, which may be related to the different reaction functions of monetary authorities to asset price movements in these economies.

Finally, real exchange rates appreciate in the case of the euro area, the U.K. and the rest of Europe, while they depreciate in China and in Japan. Like in the previous simulations, the Japanese yen tends to depreciate in response to an adverse equity price shock.

5.3 Shock to U.S. Real GDP

Table 19 reports the GIRFs for a one standard error negative shock on U.S. GDP, equivalent to a 0.5-0.6% decrease in U.S. real output. In the simulation, the real output shock is associated with a slight decrease in U.S. inflation and a decrease in real equity prices (by slightly more than 1%) and short-term interest rates (by around 60 basis points). Although this shock cannot be interpreted as an orthogonalized shock, as we have not imposed any structure on the GVAR, we can however interpret it, given the signs of the different responses, as a U.S. demand shock. This simulation also provides insights into the transmission of real shocks across countries.

The transmission of the shock appears to be relatively slow. On impact, real GDP in the euro area, the U.K. and the rest of Europe is reduced by about 1/10 the shock on the U.S.. Over time, the shock propagation increases. In the first year, on average, real GDP decreases by around 0.1% in the euro area and the U.K., and by around 0.05% in the rest of Europe and Japan. China is the only region benefiting from the negative U.S. shock. In the second year, the response of the shock in the euro area and in Japan is around one third of that in the U.S. (around one fifth for the U.K. and the rest of Europe). Given the weight of the U.S. in the euro area trade (around 20%) and the openness ratio of the euro area, these results clearly indicate that other channels play an important role in the transmission of shocks.

Among the other channels, the financial linkages appear to be of importance. Interestingly, the equity markets in the different regions overreact to the change in U.S. real GDP growth. While U.S. real equity prices decrease by 1.2% on average in the first year and by 1.1% in the second year, the other markets react much more strongly (with a maximum of 1.8% in the euro area, 2.6% in the rest of Europe and 1.1% in Japan). This over-reaction is likely to explain the relatively strong reaction of real output. The U.K. equity market appears instead to be less affected.

Concerning the real exchange rates, all currencies tend to appreciate vis-a-vis the U.S. dollar, the Japanese yen reacting in the same way as the other currencies. The reaction of interest rates is also very similar across countries and regions. Short-term interest rates and interest rate spreads decrease by around 20 basis points. It is worth pointing out that the reactions of exchange rates remain very small considering the volatility of exchange rate markets to news related to U.S. GDP. Their responses are also much smaller than those of equity markets. The Chinese real exchange rate does not react to the shock. Hence, the Chinese economy tends to gain market shares with respect to the countries and regions outside the U.S.. This may partly explain the positive response of China's real GDP.

5.4 Shock to U.S. Short-Term Interest Rate

Table 20 presents results over the two first years of a positive one standard error shock on U.S. short-term interest rates. Although it is difficult to interpret this shock as a monetary policy shock, this simulation shows usual changes in the other variables while interest rates increase. In the U.S., the one standard error positive shock is equivalent to a 0.2% increase in short term interest rates (i.e. around 80 basis points). This increase is associated with an increase in real output of 0.2% on impact. Real GDP then decreases gradually and remains at around 0.1% below baseline levels after 8 quarters. Higher inflation also accompanies the interest rate increase, though the magnitude remains limited. Real equity prices fall by 0.6% on average in the first year and by 0.7% in the second year.

This association of changes in U.S. variables has some effects on the other countries and regions. Interest rates tend to rise in the rest of the world although their increase is modest compared to the U.S. interest rate change. Hence, while monetary policy changes in the U.S. and in the rest of the world tend to move in the same direction, the extent of the comovements appears to be limited.

Regarding real output, the U.S. interest rate shock has a negative effect on the other countries, the U.K. being the only exception. Real exchange rates depreciate following a U.S. interest rate increase, although limited in range. Inflation does not react significantly to the shock. Equity markets follow the U.S. responses, some countries overreacting to the U.S. equity market changes.

6 Structural Impulse Response Analysis Using the GVAR Model

Structural identification of all the 134 different shocks (the total number of endogenous variables) in the GVAR model will be a formidable undertaking, and might not be necessary since in practice monetary policy, demand and supply shocks are likely to be highly correlated across countries. In what follows we focus on identification of shocks to the U.S. economy, particularly the monetary policy shocks, and consider the time profiles of their effects on the euro area. To this end we include the U.S. model as the first country model and following Sims (1980), consider alternative orderings of the variables within the U.S. model. The outcome of this exercise will be invariant to the ordering of the rest of the variables in the GVAR model, so long as the contemporaneous correlations of these shocks are left unrestricted (both in relation to themselves and with respect to the U.S. shocks). Ordering of the rest of the variables in the GVAR model will be important for the analysis of the U.S. monetary policy shocks, only if short-run over-identifying restrictions are imposed on the parameters of the models.

In the light of the arguments advanced in Sims and Zha (1998), one possible identification scheme for the U.S. pursued below, is to adopt the ordering of the variables in the U.S. model as follows:

\mathbf{x}_{0t} = (oil, short-term interest rate, long-term interest rate, equity prices, inflation and output). It is also assumed that variance matrix of the structural errors ($\boldsymbol{\varepsilon}_{0t}$) associated to these variables are orthogonal.⁹

Consider the $VARX^*(1)$ model for the U.S. denoted by the country index $i = 0$,

$$\mathbf{x}_{0t} = \boldsymbol{\Phi}_0 \mathbf{x}_{0,t-1} + \boldsymbol{\Psi}_{01} \mathbf{x}_{0t}^* + \boldsymbol{\Psi}_{02} \mathbf{x}_{0,t-1}^* + \mathbf{u}_{0t}. \quad (18)$$

Premultiply (18) by \mathbf{P}_0 ,

$$\mathbf{P}_0 \mathbf{x}_{0t} = \mathbf{P}_0 \boldsymbol{\Phi}_0 \mathbf{x}_{0,t-1} + \mathbf{P}_0 \boldsymbol{\Psi}_{01} \mathbf{x}_{0t}^* + \mathbf{P}_0 \boldsymbol{\Psi}_{02} \mathbf{x}_{0,t-1}^* + \mathbf{P}_0 \mathbf{u}_{0t}$$

where

$$\boldsymbol{\varepsilon}_{0t} = \mathbf{P}_0 \mathbf{u}_{0t}$$

are the structural shocks. The identification conditions a la Sims(1980) are given by

$$\begin{aligned} Cov(\boldsymbol{\varepsilon}_{0t}) &: \text{diagonal} \\ \mathbf{P}_0 &: \text{lower triangular} \end{aligned}$$

$$\begin{aligned} Cov(\mathbf{u}_{0t}) &= \boldsymbol{\Sigma}_{u0} = \mathbf{Q}'_0 \mathbf{Q}_0 \\ Cov(\boldsymbol{\varepsilon}_{0t}) &= \boldsymbol{\Sigma}_{\varepsilon 0} = \mathbf{P}_0 \boldsymbol{\Sigma}_{u0} \mathbf{P}'_0. \end{aligned}$$

where \mathbf{Q}_0 is the upper Cholesky factor of $\boldsymbol{\Sigma}_{u0}$. Hence

$$\mathbf{P}_0 \boldsymbol{\Sigma}_{u0} \mathbf{P}'_0 = \mathbf{P}_0 \mathbf{Q}'_0 \mathbf{Q}_0 \mathbf{P}'_0 = \boldsymbol{\Sigma}_{\varepsilon 0},$$

and

$$\mathbf{P}_0 \mathbf{Q}'_0 = \boldsymbol{\Sigma}_{\varepsilon 0}^{1/2}, \text{ a diagonal matrix.} \quad (19)$$

Consider now the GVAR model

$$\mathbf{G} \mathbf{x}_t = \mathbf{H} \mathbf{x}_{t-1} + \dots + \mathbf{u}_t, \quad (20)$$

Define

$$\mathbf{P}_G^0 = \begin{pmatrix} \mathbf{P}_0 & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{I} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \ddots & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{I} \end{pmatrix} \quad (21)$$

⁹An alternative approach that could be explored is that of Christiano, Eichenbaum and Evans (1999). We could also consider non-recursive identification schemes. The mathematical treatment will be the same. Only the form of \mathbf{P}_0 and the variance matrix of $\boldsymbol{\varepsilon}_{0t}$ will be different.

Premultiply (20) by (21),

$$\mathbf{P}_G^0 \mathbf{G} x_t = \mathbf{P}_G^0 \mathbf{H} \mathbf{x}_{t-1} + \dots + \boldsymbol{\varepsilon}_t,$$

where

$$\boldsymbol{\varepsilon}_t = \begin{pmatrix} \boldsymbol{\varepsilon}_{0t} \\ \mathbf{u}_{1t} \\ \vdots \\ \mathbf{u}_{Nt} \end{pmatrix},$$

$$\boldsymbol{\Sigma}_\varepsilon = Cov(\boldsymbol{\varepsilon}_t) = \begin{pmatrix} V(\boldsymbol{\varepsilon}_{0t}) & Cov(\boldsymbol{\varepsilon}_{0t}, \mathbf{u}_{1t}) & \cdots & Cov(\boldsymbol{\varepsilon}_{0t}, \mathbf{u}_{Nt}) \\ Cov(\mathbf{u}_{1t}, \boldsymbol{\varepsilon}_{0t}) & V(\mathbf{u}_{1t}) & \cdots & Cov(\mathbf{u}_{1t}, \mathbf{u}_{Nt}) \\ \vdots & \vdots & \ddots & \vdots \\ Cov(\mathbf{u}_{Nt}, \boldsymbol{\varepsilon}_{0t}) & Cov(\mathbf{u}_{Nt}, \mathbf{u}_{1t}) & \cdots & V(\mathbf{u}_{Nt}) \end{pmatrix} \quad (22)$$

with

$$\begin{aligned} V(\boldsymbol{\varepsilon}_{0t}) &= \boldsymbol{\Sigma}_{\varepsilon,00} = \mathbf{P}_0 \widehat{\boldsymbol{\Sigma}}_{u,00} \mathbf{P}_0', \\ Cov(\boldsymbol{\varepsilon}_{0t}, \mathbf{u}_{jt}) &= Cov(\mathbf{P}_0 \mathbf{u}_{0t}, \mathbf{u}_{jt}) = \mathbf{P}_0 \boldsymbol{\Sigma}_{u,0j}. \end{aligned}$$

Generalized impulse responses with respect to the structural shocks are now defined as

$$g(h, \mathbf{x} : \boldsymbol{\varepsilon}) = E(\mathbf{x}_{t+h} | \Omega_{t-1}, \mathbf{e}_i' \boldsymbol{\varepsilon}_t = \sqrt{\mathbf{e}_i' \boldsymbol{\Sigma}_\varepsilon \mathbf{e}_i}) - E(\mathbf{x}_{t+h} | \Omega_{t-1}).$$

But, the contemporaneous effects are

$$\mathbf{P}_G^0 \mathbf{G} E(\mathbf{x}_t | \Omega_{t-1}, \mathbf{e}_i' \boldsymbol{\varepsilon}_t = \sqrt{\mathbf{e}_i' \boldsymbol{\Sigma}_\varepsilon \mathbf{e}_i}) = \mathbf{P}_G^0 \mathbf{H} \mathbf{x}_{t-1} + \frac{\boldsymbol{\Sigma}_\varepsilon \mathbf{e}_i}{\sqrt{\mathbf{e}_i' \boldsymbol{\Sigma}_\varepsilon \mathbf{e}_i}}$$

where \mathbf{e}_i is a selection vector applied to all the elements of \mathbf{x}_t .

Thus, the contemporaneous effects are given by

$$g(0, \mathbf{x} : \boldsymbol{\varepsilon}_0) = \frac{(\mathbf{P}_G^0 \mathbf{G})^{-1} \boldsymbol{\Sigma}_\varepsilon \mathbf{e}_i}{\sqrt{\mathbf{e}_i' \boldsymbol{\Sigma}_\varepsilon \mathbf{e}_i}} = \frac{\mathbf{G}^{-1} (\mathbf{P}_G^0)^{-1} \boldsymbol{\Sigma}_\varepsilon \mathbf{e}_i}{\sqrt{\mathbf{e}_i' \boldsymbol{\Sigma}_\varepsilon \mathbf{e}_i}}.$$

The impulse responses for other horizons can be derived using the same recursive relations used for the computation of the generalized impulse responses.

Under the orthogonalization scheme, $\boldsymbol{\Sigma}_\varepsilon$, defined by (22), is specified as

$$V(\boldsymbol{\varepsilon}_{0t}) = \mathbf{I}_{k_\sigma},$$

while the following options can be entertained

$$Cov(\boldsymbol{\varepsilon}_{0t}, \mathbf{u}_{jt}) = 0, \quad (23)$$

or

$$Cov(\boldsymbol{\varepsilon}_{0t}, \mathbf{u}_{jt}) = \mathbf{P}_0 \boldsymbol{\Sigma}_{u,0j}, \quad (24)$$

for $j = 1, 2, \dots, N$. Under this specification, using (19) we have

$$\mathbf{P}_0 = (\mathbf{Q}'_0)^{-1},$$

and hence

$$(\mathbf{P}_G^0)^{-1} = \begin{pmatrix} \mathbf{Q}'_0 & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{I} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \ddots & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{I} \end{pmatrix}.$$

The covariance specification, (23), imposes over-identifying restrictions, and should be used with care. By contrast (24) does not impose any further restrictions, and ensures that the impulse responses of structural shocks to the U.S. economy will be invariant to any re-ordering of the variables in the rest of the GVAR model. Also the structural impulse responses of the shocks to the oil prices (the first variable in the $VARX^*$ model of the U.S.) will be the same as the corresponding generalized impulse responses.¹⁰ The same, however, will not be true of the other structural impulse responses. Note also that these results will not hold under the restricted (over-identified) covariance specification (23).

6.1 Comparisons of Structural and Generalized Impulse Responses

We shall continue to consider structural shocks corresponding to the four shock scenarios discussed in Section 5, and focus only on their effects on the euro area variables. We will start first with the exact identification scheme, and then consider the sensitivity of the results to alternative orderings of the variables in the U.S. model.

6.1.1 Shock to Oil Prices

As shown in Pesaran and Shin (1998), a shock to the oil price (the first variable in the U.S. model) will yield the same IRFs in the structural exactly identified case as in the case of the GIRFs. The IRFs will, however, differ in the overidentified case. Figure 1 shows the impacts of a positive one s.d. shock to oil prices on U.S. and euro area variables, comparing the exactly-identified and the over-identified cases. For output in the U.S., the response is very similar in these two cases, while for the euro area, the over-identified response is slightly less negative in the short-run. For inflation, equity prices and interest rates, the IRFs are broadly equivalent irrespective of the identification method. Only exchange rate reactions seem to differ: in the exactly identified case, the real appreciation of the euro is less pronounced compared with the overidentified one in the short term; the euro even depreciates after one year.

¹⁰See, Pesaran and Shin (1998).

6.1.2 Shock to U.S. Equity Prices

As shown in Figure 2, identification of the equity price shock does not change significantly the shape of the impulse response functions. The only significant difference concerns oil prices which decrease twice as much as in the non-identified case. This difference partly explains the larger response of inflation in the case of structural shocks. Indeed, for the U.S., while in the GIRF case inflation increases in the short term before decreasing after 3 quarters, the fall in the inflation rate is faster and larger.

Comparing exactly identified and overidentified impulse responses (Figure 3) does not yield significant differences. The impact on interest rates tends to be slightly larger in the overidentified case, both in the U.S. and in the euro area. The impact on output and on equity prices is also more pronounced in the overidentified case for the euro area. This difference may also explain the reduction in the real appreciation of the euro when going from the exactly identified case to the overidentified one.

6.1.3 Shock to U.S. Real GDP

While under the two previous shock scenarios the impulse responses did not change much, there are noticeable differences between the GIRF and the identified case. As shown in Figure 4, the U.S. real GDP shock is smaller in the exactly identified case compared with the non-structural one : U.S. real GDP decreases by 0.4 percent and converges progressively towards a 0.25% difference with respect to the baseline, while the reduction in the case of the non-structural shock amounts to 0.4% in the long run). In the euro area, the impact on real GDP is also smaller. However, the multiplier between the U.S. and the euro area response on GDP is broadly similar (around 0.4). The inflation response tends to be large in the short run, and larger compared with the non-identified shock. Another interesting result concerns the interest rates impacts. Compared with the non-structural impulse responses, the structural one features a rather modest decrease in interest rates, both in the U.S. (five times less) and in the euro area (twice less). Unlike the non-structural impulse responses, the exactly identified shocks imply a real appreciation of the euro in the short run. The equity prices tend also to increase in the euro area in the short term, before decreasing in the long run.

The comparison between the structural impulse responses (between exactly identified and overidentified) is shown in Figure 5. Although the shock on U.S. GDP is broadly equivalent in both cases, the overidentified shocks tend to trigger larger responses on euro area GDP, U.S. interest rates and oil prices. On the contrary, the responses are less pronounced for equity prices. Like in the non-identified case, the long run response of euro area inflation is negative, while it is positive in the exactly identified case.

6.1.4 U.S. Monetary Policy Shocks and Sensitivity of the Impulse Responses to Alternative Orderings

The identification of the shock to U.S. short-term interest rates allows us to treat it as a U.S. monetary policy shock. This shock leads to similar results when comparing non-structural and structural (exactly identified) responses (see Figure 6). U.S. real output increases in the short-run before decreasing permanently by around 0.2%. The main differences concern equity prices, where the responses are smaller in the structural case and oil prices, where the structural responses feature a small decrease in oil prices, while the non-structural responses feature an increase in oil prices.

The overidentified shock triggers rather different responses (see Figure 7). While for the U.S., the results are similar, their impact on the euro area are significantly different. First, real GDP and inflation increase, while they both decreased in the exactly identified case. The interest rate reaction is also greater in the overidentified case. On the other hand, both exchange rate and oil prices are barely affected by the overidentified shock. These results should be viewed with caution since the over-identifying restrictions might not be supported by the available evidence.

We performed sensitivity analysis of the U.S. monetary policy shocks by experimenting with different orderings (see Figure 8). We define ordering A, the one examined in the preceding analysis, as $\mathbf{x}_{0t}^A = (\text{oil, short-term interest rate, long-term interest rate, equity prices, inflation and output})$. Two alternative orderings are investigated, namely ordering B defined as $\mathbf{x}_{0t}^B = (\text{oil, equity, short-term interest rate, long-term interest rate, output and inflation})$ and ordering C defined as $\mathbf{x}_{0t}^C = (\text{oil, equity, long-term interest rate, short-term interest rate, output and inflation})$.

While orderings A and B yield similar impulse responses, ordering C implies some noticeable differences. First, while the interest rate shock is slightly smaller than the ones implied by the other orderings, the impact on real GDP is greater. On the contrary, the financial variables are less affected (the equity prices barely change and the spread increases only marginally). Oil prices, however, exhibit a sharper decrease compared to the other two orderings.

The short-term positive response, which is present irrespective of the ordering, may appear difficult to justify in the context of a monetary policy shock. However, Christiano, Eichenbaum and Evans (1999) show that such a response can be expected when output comes after the monetary policy variables in the ordering of variables, which is actually the case in orderings A, B and C. Moreover, the short-term positive effects on inflation we find is consistent with the finding that took the name in the literature of price puzzle (Sims, 1992; Eichenbaum, 1992). However, this puzzle is present despite the inclusion of the oil price in the model, contradicting Sims and Zha (1998), who show that the price puzzle often disappears when introducing a commodity price. It is clearly worth considering other identification schemes developed in the VAR literature in order to evaluate the extent to which the price puzzle is a “reality” or simply a reflection of the particular identification strategy adopted.

7 Robustness of the GVAR Results to Time-Varying Weights

The preceding analysis was carried out using fixed trade weights on the grounds that changes in trade weights tend to be rather gradual and secular changes in trade weights are often counter acted by the comovements of the macroeconomic variables so that the foreign-specific variables computed using fixed and variable trade weights are often very close. To check the robustness of our results to the choice of trade weights we also estimated the GVAR model using rolling three-year moving averages of the annual trade weights.¹¹ But before presenting some of these results it would be instructive first to provide some evidence on the relationship of the two measures, \mathbf{x}_{it}^* (based on fixed weights) and \mathbf{x}_{it}^{**} (based on the time-varying weights). Since both measures are likely to be $I(1)$, in Tables 21, 22 and 23 we summarize the correlation coefficients of the levels as well as their first differences. In terms of the levels the two measures are very high, in many cases close to unity. In terms of their first difference, the correlations are not as high, particularly in the case of nominal magnitudes such as inflation and interest rates. Given these results, it seems unlikely that the main conclusions of the paper would be much affected by choice of the trade weights.

To check this conjecture we re-estimated the GVAR model using the same lag orders for the individual country models, and obtained very similar number of cointegrating relations. The differences between the two sets of results were Japan (3 cointegrating relations as compared to 5 previously), United Kingdom (2 instead of 3), and Sweden (4 instead of 3). See Table 24. We obtained the same number of cointegrating relations for the remaining countries.

Turning to the impact effects of the foreign variables, the estimates (together with their standard errors) are summarized in Table 25, and are comparable to the corresponding estimates based on fixed trade weights given in Table 10. The two estimates are generally close and yield similar qualitative conclusions. This is particularly so in the case of real equity prices and long-term interest rates. The results for output are also very close with the exception of the estimates obtained for Norway. Not surprisingly, the results have been affected most in the case of China, where none of the estimates based on the time-varying weights are now statistically significant, as compared to the two statistically significant estimates obtained when using the fixed weights.

Similar conclusions are also reached if one considers average pair-wise cross section correlations of the residuals or the impulse responses under the two weighting schemes. Estimates of the average cross section correlations of the residuals for the two sets of weights are summarized in Tables 26 to 31.

¹¹The process of computing time-varying trade weights was initialized by using the same set of weights for the first three years of our sample period.

We also compared a variety of impulse responses based on fixed and time-varying trade weights, and found that in general, the results are very close. Even when they differ quantitatively, the main conclusions reached using the fixed weights tend to hold qualitatively.

Overall, the main results of the paper seem to be reasonably robust to the choice of the trade weights. In view of these results, it might be a good idea to combine the simplicity of the fixed weights with the up-to-date nature of the time varying weights by selecting three sets of weights to be used at the start, in the middle, and towards the end of the sample. Trade weights that vary continuously could mask the underlying movements of the macroeconomic variables that go into the construction of the foreign variables.

8 GVAR and Structural Breaks

One of the fundamental problems facing econometric modeling is the possibility of structural breaks. The problem is likely to be particularly acute in the case of emerging economies that are subject to significant political and social change. The GVAR model is clearly not immune to this problem. Unfortunately, despite the great deal of recent research in this area, there is little known about how best to model breaks. Even if in-sample breaks are identified using Bayesian or classical procedures, there are insurmountable difficulties in allowing for the possibility of future breaks in forecasting and policy analysis. It is, therefore, perhaps not surprising that so far we have been silent on this important and troubling issue. It is an area that deserves special attention, but it is beyond the scope of the present paper. Longer time series might also be needed for this purpose.

However, the fact that country-specific models within the GVAR framework are specified conditional on foreign variables should help in alleviating the structural problem somewhat. Consider, for example, the real equity price equations in the individual country models and suppose that there is a market crash that results in breaks in the U.S. equity return equation. Although, in this case the U.S. model will be subject to breaks, there is no reason to believe that equity return equations in the other country models should also be subject to similar breaks. This is due to the possibility of “co-breaking” across markets; a concept introduced in macroeconometric modelling by Hendry (1996) and examined further by Hendry and Mizon (1998). The structure of the GVAR can readily accommodate co-breaking and suggests that the VARX* models that underlie the GVAR might be more robust to the possibility of structural breaks as compared to country VAR models. The analysis of structural breaks can then focus on the U.S. or other economic regions in which the break(s) might have originated.

9 Concluding Remarks

This paper updates and extends the GVAR model of Pesaran, Schuermann and Weiner (2004) in a number of directions, provides an unobserved common factor interpretation of the country-specific foreign variables included in the GVAR, and shows how the model can be used for structural impulse response analysis.

Compared to the original version of the GVAR, the current version extends the geographical coverage from 11 country/regions to 25 countries with the euro area being treated as a single economy, updates the estimation period to the end of 2003 (from end of 1999 previously), includes the long-term interest rate as an endogenous variable in country-specific models, and includes oil prices as an endogenous variable in the U.S. model rather than treat it as a global exogenous variable. Also, the U.S. model now allows for feedback effects from changes in output and inflation outside the U.S. variables.

The current version, therefore, captures more fully the interactions in the world economy and includes new channels of transmissions via changes in the term premia, the feedback effects on oil prices from the global economy, and the changes in output and inflation from the rest of the world to the U.S. economy.

Although, the new GVAR model can be used for many different purposes, in this paper we have focussed on the short term and long term implications of external shocks for the euro area economy. We provide impact effects of external changes in interest rates (short and long rates), inflation, output, real equity prices, real exchange rates and oil prices on the euro area and present the time profiles of these shocks using both generalized and structural impulse response functions.

The key to the GVAR modeling is the systematic inclusion of the country-specific foreign variables in the individual country models in order to deal with the common factor dependencies that exist in the world economy. The average pair-wise cross-section correlations computed for the endogenous variables, their first differences, and the residuals from the GVAR model show that very little cross section correlations remain once the effects of foreign variables have been taken into account. This is in line with the results of the tests of weak exogeneity of the foreign variables also reported in the paper.

In addition to generalized impulse response functions, we also consider structural identification of shocks in the global economy, and emphasize that unlike the GIRFs, the results of structural impulse responses in general depend on the order in which different countries are included in the GVAR model. It is partly for this reason that in our structural impulse response analyses we focus on identification of shocks to the U.S. economy, which we order as the first economy in the GVAR model. In particular, we consider the short term and long term effects of a U.S. monetary policy shock on the euro area.

From a policy analysis perspective, a number of interesting results emerge:

The simulations clearly show that financial shocks (equity and bond prices) tend to be transmitted much faster than shocks to real output and/or inflation, and often get amplified as they travel from the U.S. to the euro area and the rest of the world. Equity and bond markets seem to be far more synchronous

as compared to the foreign exchange markets. The cross country dependence of exchange rates is rather weak and hardly changes as a result of the GVAR modeling. Further research is clearly needed for a better understanding of the factors that lie behind exchange rate interdependencies. The instability of the cross market correlations over time could also be an important factor in such an explanation.

Transmission of real shocks is rather slow, normally taking 2-3 years, or in some cases even more, before their full impacts are felt. The long run impacts of the real shocks are, however, larger than what might be expected from a simple trade perspective. Regarding output and inflation shocks, the trade linkages appear to work first, leading the shocks to be transmitted in a gradual manner with their effects being spread over 2-3 years. The effects of output shocks across countries is less synchronous than inflation shocks, which is still less synchronous than the effects of shocks to financial variables.

Comparing the effects of the shocks on the euro area economy and the rest of Europe, the results show striking similarities. The same applies to the U.K. although to a lesser extent. One noticeable difference concerns the exchange rate response. The U.K. real exchange rate tends to deviate less from the U.S. dollar than the euro.

The model also highlights the importance of second, and even third round effects of the shocks (particularly the financial ones). A shock in the U.S. can be amplified because the U.S. will also be affected over time through the return impacts of output and inflation shocks in the rest of the world. The euro area in turn reacts to the U.S. shocks directly as well as indirectly through the impact of the U.S. shocks on euro area trade partners, and so on. The transmission of shocks does not take place only through trade, but also more importantly through the impact of real shocks on financial variables with subsequent spillover effects on real variables.

The GVAR presents a complicated, yet simple to follow, spatiotemporal structure for the analysis of the world economy. To be sure it can be modified and extended further. But it is hoped that the present version makes a further step towards the development of a transparent and coherent framework for the analysis of global interdependencies.

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Table 17: Generalised Impulse Responses of a Negative One Standard Error Shock to Oil Prices

	Quarters									Average	Average
	0	1	2	3	4	5	6	7	8	1 st Year	2 nd Year
Oil prices	12.33	14.01	13.78	13.41	13.66	13.72	13.98	14.01	13.99	13.38	13.84
	On real GDP (%)										
US	-0.03	-0.13	-0.18	-0.20	-0.20	-0.23	-0.24	-0.25	-0.27	-0.13	-0.23
Euro area	-0.04	-0.08	-0.05	-0.05	-0.04	-0.03	-0.02	-0.01	-0.01	-0.06	-0.03
China	0.03	0.13	0.24	0.32	0.38	0.42	0.44	0.45	0.46	0.18	0.42
Japan	0.08	0.16	0.19	0.21	0.21	0.25	0.29	0.31	0.34	0.16	0.27
UK	-0.08	-0.06	-0.05	-0.09	-0.11	-0.12	-0.14	-0.17	-0.20	-0.07	-0.14
Rest Europe	-0.04	-0.11	-0.02	-0.02	0.00	0.00	0.02	0.03	0.02	-0.05	0.01
	On inflation (%)										
US	0.21	0.16	0.11	0.11	0.12	0.11	0.11	0.12	0.11	0.15	0.11
Euro area	0.10	0.05	0.05	0.04	0.06	0.06	0.06	0.07	0.06	0.06	0.06
China	0.05	-0.33	-0.27	-0.02	0.00	-0.11	-0.20	-0.13	-0.11	-0.13	-0.11
Japan	0.01	0.12	0.08	0.16	0.13	0.16	0.14	0.17	0.15	0.09	0.15
UK	0.17	-0.11	0.07	-0.01	0.03	0.06	0.03	0.07	0.06	0.03	0.05
Rest Europe	0.15	0.06	0.15	0.11	0.11	0.10	0.11	0.12	0.11	0.12	0.11
	On real equity prices (%)										
US	-1.07	-1.84	-2.14	-2.17	-2.31	-2.35	-2.44	-2.50	-2.54	-1.81	-2.40
Euro area	-1.96	-4.30	-4.79	-5.09	-5.15	-5.33	-5.43	-5.45	-5.52	-4.04	-5.34
Japan	-0.06	-1.83	-2.32	-2.84	-2.95	-3.32	-3.54	-3.77	-3.90	-1.76	-3.39
UK	-0.39	-1.43	-1.67	-1.95	-2.02	-2.23	-2.37	-2.47	-2.59	-1.36	-2.27
Rest Europe	-1.62	-3.78	-4.23	-4.01	-4.07	-3.98	-4.00	-4.01	-4.01	-3.41	-4.02
	On interest rate (%)										
US	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.03	0.04
Euro area	0.01	0.03	0.03	0.03	0.03	0.04	0.04	0.05	0.05	0.02	0.04
China	0.01	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.02	0.03
Japan	0.01	0.03	0.06	0.09	0.11	0.13	0.15	0.16	0.17	0.05	0.14
UK	-0.04	0.01	-0.04	-0.03	-0.03	-0.02	-0.01	-0.01	0.00	-0.02	-0.02
Rest Europe	0.00	0.06	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02
	On real exchange rate (%)										
Euro area	0.18	-0.42	-0.06	0.17	0.24	0.19	0.21	0.22	0.24	-0.03	0.21
China	-0.52	-0.83	-0.90	-1.21	-1.34	-1.44	-1.40	-1.47	-1.57	-0.86	-1.41
Japan	1.21	1.53	2.52	3.33	3.75	3.98	4.07	4.06	4.04	2.15	3.96
UK	-0.22	-0.44	-0.76	-0.30	0.18	0.57	0.76	0.86	0.90	-0.43	0.59
Rest Europe	0.04	-0.66	-0.59	-0.56	-0.58	-0.58	-0.59	-0.55	-0.54	-0.44	-0.58
	On interest rate spreads (%)										
US	0.03	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.04	0.05
Euro area	0.03	0.04	0.04	0.04	0.05	0.05	0.06	0.07	0.07	0.04	0.06
Japan	0.04	0.04	0.06	0.07	0.09	0.10	0.11	0.11	0.12	0.05	0.10
UK	0.02	0.02	0.01	0.01	0.02	0.03	0.03	0.04	0.04	0.01	0.03
Rest Europe	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.04	0.05

Table 18: Generalised Impulse Responses of a Negative One Standard Error Shock to US Equity Prices

	Quarters									Average	Average
	0	1	2	3	4	5	6	7	8	1 st Year	2 nd Year
Oil prices	2.02	-0.49	-2.76	-2.92	-3.19	-3.75	-4.09	-4.22	-4.32	-1.04	-3.81
	On real GDP (%)										
US	-0.12	-0.37	-0.52	-0.58	-0.62	-0.64	-0.63	-0.60	-0.57	-0.40	-0.62
Euro area	0.04	-0.07	-0.17	-0.25	-0.33	-0.38	-0.42	-0.45	-0.47	-0.11	-0.40
China	0.03	0.10	0.17	0.26	0.36	0.45	0.54	0.62	0.70	0.14	0.49
Japan	0.07	0.03	-0.07	-0.18	-0.28	-0.35	-0.41	-0.47	-0.52	-0.04	-0.38
UK	-0.04	-0.06	-0.16	-0.25	-0.30	-0.32	-0.33	-0.33	-0.32	-0.13	-0.32
Rest Europe	-0.15	-0.26	-0.40	-0.49	-0.53	-0.57	-0.56	-0.56	-0.56	-0.33	-0.55
	On inflation (%)										
US	0.05	-0.01	-0.08	-0.09	-0.08	-0.09	-0.09	-0.09	-0.08	-0.03	-0.09
Euro area	-0.03	-0.03	-0.05	-0.03	-0.02	-0.04	-0.05	-0.05	-0.06	-0.03	-0.04
China	0.20	-0.22	-0.37	-0.01	0.13	0.02	0.00	0.07	0.10	-0.10	0.05
Japan	-0.11	-0.02	-0.10	-0.05	-0.07	-0.06	-0.09	-0.07	-0.09	-0.07	-0.07
UK	-0.03	-0.14	-0.02	-0.21	-0.09	-0.11	-0.13	-0.12	-0.12	-0.10	-0.11
Rest Europe	-0.04	0.06	0.01	-0.03	-0.01	-0.05	-0.05	-0.05	-0.06	0.00	-0.04
	On real equity prices (%)										
US	-5.71	-7.30	-7.34	-7.32	-7.16	-6.93	-6.70	-6.55	-6.41	-6.92	-6.83
Euro area	-5.48	-7.71	-8.72	-9.46	-9.71	-9.87	-9.72	-9.56	-9.36	-7.84	-9.72
Japan	-2.63	-5.27	-5.90	-5.89	-5.67	-5.58	-5.46	-5.37	-5.32	-4.92	-5.52
UK	-4.82	-5.88	-6.30	-6.31	-6.11	-5.99	-5.71	-5.52	-5.32	-5.83	-5.83
Rest Europe	-4.79	-7.47	-8.57	-9.35	-9.82	-9.99	-9.90	-9.77	-9.64	-7.55	-9.87
	On interest rate (%)										
US	0.00	-0.05	-0.10	-0.12	-0.14	-0.16	-0.16	-0.17	-0.17	-0.07	-0.16
Euro area	0.00	-0.01	-0.02	-0.04	-0.06	-0.07	-0.09	-0.10	-0.11	-0.02	-0.08
China	0.01	0.00	0.01	0.00	0.01	0.02	0.03	0.03	0.04	0.01	0.02
Japan	0.00	-0.01	-0.02	-0.03	-0.03	-0.04	-0.04	-0.04	-0.04	-0.01	-0.04
UK	-0.03	-0.03	-0.07	-0.08	-0.10	-0.11	-0.12	-0.13	-0.14	-0.05	-0.12
Rest Europe	0.04	0.05	0.03	0.02	0.00	-0.01	-0.03	-0.04	-0.05	0.04	-0.02
	On real exchange rate (%)										
Euro area	-1.24	-1.70	-1.66	-1.64	-1.58	-1.52	-1.39	-1.32	-1.30	-1.56	-1.46
China	0.16	0.26	0.43	0.37	0.24	0.27	0.24	0.15	0.03	0.30	0.22
Japan	0.01	0.35	1.00	1.13	1.16	1.14	1.11	0.98	0.84	0.62	1.10
UK	-0.66	-0.58	-0.52	0.00	0.28	0.34	0.35	0.29	0.21	-0.44	0.32
Rest Europe	-1.52	-2.09	-2.17	-2.24	-2.20	-2.16	-2.05	-1.99	-1.95	-2.00	-2.10
	On interest rate spreads (%)										
US	0.01	-0.01	-0.03	-0.05	-0.06	-0.08	-0.09	-0.09	-0.10	-0.02	-0.08
Euro area	0.00	-0.02	-0.04	-0.05	-0.06	-0.08	-0.08	-0.09	-0.10	-0.03	-0.08
Japan	-0.01	-0.03	-0.04	-0.04	-0.05	-0.06	-0.06	-0.06	-0.06	-0.03	-0.06
UK	0.02	0.01	-0.01	-0.02	-0.03	-0.04	-0.05	-0.06	-0.06	0.00	-0.05
Rest Europe	0.01	0.00	-0.02	-0.03	-0.04	-0.05	-0.05	-0.06	-0.06	-0.01	-0.05

Table 19: Generalised Impulse Responses of a Negative One Standard Error Shock to US Real GDP

	Quarters									Average	Average
	0	1	2	3	4	5	6	7	8	1 st Year	2 nd Year
Oil prices	0.91	-1.14	-1.59	-1.58	-1.46	-1.56	-1.67	-1.76	-1.79	-0.85	-1.61
	On real GDP (%)										
US	-0.50	-0.56	-0.57	-0.54	-0.51	-0.50	-0.47	-0.46	-0.44	-0.54	-0.48
Euro area	-0.03	-0.07	-0.08	-0.11	-0.12	-0.13	-0.14	-0.15	-0.16	-0.07	-0.14
China	0.04	0.12	0.21	0.28	0.36	0.43	0.49	0.54	0.50	0.16	0.45
Japan	0.06	-0.01	-0.05	-0.07	-0.09	-0.12	-0.15	-0.17	-0.19	-0.02	-0.13
UK	-0.07	-0.05	-0.08	-0.09	-0.09	-0.09	-0.10	-0.09	-0.10	-0.07	-0.09
Rest Europe	-0.07	-0.02	-0.03	-0.07	-0.08	-0.07	-0.06	-0.06	-0.06	-0.05	-0.07
	On inflation (%)										
US	0.01	-0.03	-0.04	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-0.01
Euro area	0.04	-0.03	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
China	0.10	-0.02	0.03	0.11	0.10	0.08	0.09	0.13	0.13	0.06	0.10
Japan	0.03	-0.04	-0.04	-0.06	-0.05	-0.06	-0.05	-0.06	-0.05	-0.03	-0.06
UK	0.02	-0.02	-0.06	0.00	-0.03	0.00	0.00	0.00	0.00	-0.02	0.00
Rest Europe	0.05	-0.02	-0.01	-0.01	-0.02	-0.01	-0.02	-0.02	-0.02	0.00	-0.02
	On real equity prices (%)										
US	-1.09	-1.27	-1.16	-1.16	-1.22	-1.13	-1.09	-1.02	-0.98	-1.17	-1.11
Euro area	-0.80	-1.37	-1.32	-1.52	-1.83	-1.83	-1.85	-1.76	-1.74	-1.25	-1.82
Japan	-0.57	-1.10	-1.13	-1.03	-1.00	-0.96	-0.85	-0.76	-0.72	-0.96	-0.89
UK	0.03	-0.29	-0.18	-0.26	-0.43	-0.37	-0.39	-0.31	-0.32	-0.17	-0.38
Rest Europe	-1.50	-2.15	-2.09	-2.22	-2.56	-2.62	-2.64	-2.59	-2.56	-1.99	-2.60
	On interest rate (%)										
US	-0.07	-0.13	-0.14	-0.14	-0.14	-0.14	-0.15	-0.15	-0.15	-0.12	-0.15
Euro area	-0.01	-0.02	-0.04	-0.05	-0.05	-0.06	-0.07	-0.07	-0.08	-0.03	-0.06
China	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.01	0.02
Japan	0.03	0.02	0.00	-0.01	-0.03	-0.04	-0.04	-0.05	-0.05	0.01	-0.04
UK	0.02	-0.01	-0.03	-0.04	-0.05	-0.05	-0.05	-0.06	-0.06	-0.02	-0.05
Rest Europe	-0.02	-0.02	-0.04	-0.05	-0.05	-0.06	-0.06	-0.06	-0.07	-0.03	-0.06
	On real exchange rate (%)										
Euro area	-0.14	-0.33	-0.23	-0.26	-0.34	-0.33	-0.34	-0.33	-0.35	-0.24	-0.33
China	-0.14	-0.07	0.05	0.03	0.01	-0.01	-0.02	-0.10	-0.16	-0.03	-0.03
Japan	-0.73	-0.99	-1.32	-1.71	-2.10	-2.27	-2.33	-2.33	-2.34	-1.19	-2.26
UK	-0.16	-0.64	-0.78	-0.77	-0.89	-1.01	-1.14	-1.23	-1.34	-0.59	-1.07
Rest Europe	-0.38	-0.55	-0.49	-0.53	-0.63	-0.62	-0.62	-0.60	-0.61	-0.49	-0.62
	On interest rate spreads (%)										
US	-0.05	-0.06	-0.06	-0.07	-0.07	-0.08	-0.08	-0.08	-0.09	-0.06	-0.08
Euro area	-0.01	-0.03	-0.04	-0.05	-0.06	-0.06	-0.07	-0.07	-0.08	-0.03	-0.06
Japan	-0.01	-0.01	-0.02	-0.03	-0.04	-0.04	-0.05	-0.05	-0.05	-0.02	-0.04
UK	-0.02	-0.04	-0.05	-0.05	-0.06	-0.06	-0.07	-0.07	-0.07	-0.04	-0.06
Rest Europe	-0.01	-0.02	-0.03	-0.03	-0.04	-0.04	-0.04	-0.05	-0.05	-0.02	-0.04

Table 20: Generalised Impulse Responses of a Negative One Standard Error Shock to US Interest rates

	Quarters									Average	Average
	0	1	2	3	4	5	6	7	8	1 st Year	2 nd Year
Oil prices	1.63	2.05	1.80	1.58	1.42	1.22	1.28	1.36	1.33	1.76	1.32
	On real GDP (%)										
US	0.19	0.27	0.13	0.02	-0.04	-0.10	-0.13	-0.15	-0.17	0.15	-0.11
Euro area	-0.01	-0.04	-0.09	-0.13	-0.15	-0.16	-0.16	-0.16	-0.15	-0.07	-0.16
China	-0.06	-0.12	-0.17	-0.22	-0.25	-0.28	-0.30	-0.31	-0.33	-0.14	-0.28
Japan	0.04	0.02	0.04	-0.04	-0.11	-0.13	-0.15	-0.18	-0.20	0.02	-0.15
UK	0.06	0.07	0.09	0.08	0.11	0.15	0.20	0.25	0.32	0.08	0.19
Rest Europe	-0.06	-0.10	-0.16	-0.18	-0.18	-0.19	-0.19	-0.18	-0.18	-0.13	-0.18
	On inflation (%)										
US	0.06	0.14	0.05	0.03	0.05	0.02	0.01	0.02	0.02	0.07	0.03
Euro area	-0.01	0.00	0.00	-0.01	-0.01	-0.03	-0.03	-0.03	-0.03	-0.01	-0.02
China	0.31	0.07	-0.30	-0.20	-0.01	0.03	-0.11	-0.13	-0.08	-0.03	-0.05
Japan	-0.06	0.06	-0.06	0.05	0.01	0.05	-0.01	0.02	0.00	0.00	0.02
UK	0.07	-0.11	0.00	-0.11	-0.07	-0.08	-0.13	-0.12	-0.12	-0.04	-0.10
Rest Europe	0.01	-0.02	0.02	0.01	0.01	-0.02	-0.02	-0.01	-0.02	0.00	-0.01
	On real equity prices (%)										
US	0.04	-0.79	-0.70	-0.54	-0.55	-0.52	-0.48	-0.52	-0.54	-0.50	-0.52
Euro area	0.09	-1.04	-1.13	-1.08	-0.77	-0.65	-0.47	-0.34	-0.21	-0.79	-0.56
Japan	-0.29	-0.91	-1.40	-1.58	-1.39	-1.56	-1.67	-1.84	-1.91	-1.05	-1.62
UK	-0.08	-0.78	-0.51	-0.17	0.33	0.59	0.93	1.19	1.43	-0.38	0.76
Rest Europe	0.32	-0.71	-0.90	-0.93	-0.85	-0.68	-0.48	-0.36	-0.22	-0.56	-0.59
	On interest rate (%)										
US	0.19	0.20	0.18	0.19	0.18	0.17	0.17	0.18	0.18	0.19	0.18
Euro area	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02
China	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.04
Japan	-0.01	0.00	0.01	0.02	0.04	0.05	0.05	0.06	0.06	0.00	0.05
UK	-0.02	0.01	0.00	0.00	-0.01	-0.02	-0.03	-0.03	-0.03	0.00	-0.02
Rest Europe	0.00	0.04	0.03	0.05	0.04	0.04	0.03	0.04	0.04	0.03	0.04
	On real exchange rate (%)										
Euro area	0.71	0.51	0.52	0.58	0.69	0.74	0.80	0.80	0.79	0.58	0.76
China	-0.84	-1.20	-1.17	-1.08	-1.22	-1.37	-1.37	-1.30	-1.34	-1.07	-1.32
Japan	0.86	1.08	1.98	2.83	3.54	3.85	3.96	3.93	3.95	1.69	3.82
UK	0.11	0.55	0.89	1.45	1.95	2.31	2.65	3.01	3.35	0.75	2.48
Rest Europe	0.41	0.16	0.20	0.30	0.45	0.53	0.58	0.60	0.61	0.27	0.54
	On interest rate spreads (%)										
US	0.04	0.04	0.04	0.04	0.04	0.46	0.04	0.05	0.05	0.04	0.04
Euro area	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.03
Japan	0.01	0.02	0.03	0.03	0.03	0.04	0.05	0.05	0.05	0.02	0.04
UK	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01
Rest Europe	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.02

Table 21: Correlation Coefficients of Country Specific Foreign Output and Inflation using Fixed and Time-Varying Trade Weights

Country	Output		Inflation	
	Levels	1st Differences	Levels	1st Differences
United States	0.999	0.931	0.885	0.677
Euro area	0.998	0.908	0.865	0.501
China	0.999	0.910	0.426	0.026
Japan	0.999	0.880	0.768	0.420
United Kingdom	1.000	0.984	0.948	0.729
Sweden	1.000	0.983	0.889	0.597
Switzerland	1.000	0.991	0.901	0.592
Norway	1.000	0.984	0.912	0.646

Table 22: Correlation Coefficients of Country Specific Foreign Real Equity Prices and Real Exchange Rates using Fixed and Time-Varying Trade Weights

Country	Real Equity Prices		Real Exchange Rates	
	Levels	1st Differences	Levels	1st Differences
United States	-	-	0.955	0.816
Euro area	0.814	0.996	0.814	0.859
China	0.868	0.980	0.868	0.669
Japan	0.852	0.985	0.852	0.629
United Kingdom	0.981	0.999	0.981	0.955
Sweden	0.975	0.999	0.975	0.956
Switzerland	0.994	0.999	0.994	0.971
Norway	0.868	0.996	0.868	0.893

Table 23: Correlation Coefficients of Country Specific Foreign Short and Long Term Interest Rates using Fixed and Time-Varying Trade Weights

Country	Short-Term Interest Rates		Long-Term Interest Rates	
	Levels	1st Differences	Levels	1st Differences
United States	-	-	-	-
Euro area	0.987	0.993	0.999	0.998
China	0.962	0.931	0.993	0.942
Japan	0.993	0.989	0.998	0.994
United Kingdom	0.999	0.989	0.999	0.998
Sweden	0.991	0.979	1.000	0.999
Switzerland	0.995	0.981	1.000	0.999
Norway	0.997	0.979	0.999	0.992

Table 24: VAR order and Number of Cointegration Relationships in the Country-Specific Models using Fixed and Time-Varying Trade Weights

Country	VAR order	Fixed Weights (99-01)	Time-Varying Weights
		# Cointegration	# Cointegration
United States	2	2	2
Euro area	2	2	2
China	2	1	1
Japan	2	5	3
United Kingdom	2	3	2
Sweden	2	3	4
Switzerland	1	3	3
Norway	2	3	3

Table 25: Contemporaneous Effects of Foreign Variables on their Domestic Counterparts using Time-Varying Trade Weights

Country	y	Domestic Variables			
		Δp	q	ρ^S	ρ^L
United States	0.449* (0.107)	0.030 (0.031)	-	-	-
Euro area	0.514* (0.100)	-0.016 (0.032)	1.109* (0.076)	0.102* (0.023)	0.695* (0.081)
China	-0.044 (0.179)	-0.121 (0.096)	-	0.020 (0.039)	-
Japan	0.146 (0.186)	0.052 (0.048)	0.532* (0.137)	0.003 (0.038)	0.406* (0.099)
United Kingdom	0.534* (0.122)	0.247 (0.165)	0.866* (0.068)	0.117 (0.153)	0.757* (0.146)
Sweden	0.492 (0.346)	0.285* (0.121)	1.251* (0.119)	1.258* (0.389)	0.852* (0.130)
Switzerland	0.444* (0.119)	0.343* (0.063)	0.693* (0.124)	0.216* (0.070)	0.432* (0.076)
Norway	0.347 (0.339)	0.337* (0.115)	1.073* (0.133)	0.178 (0.110)	0.584* (0.140)

Note: * denotes statistical significance at the 5% level or less. Standard errors are in parentheses.

Table 26: Average Pair-Wise Cross Section Correlations of the Residuals for Output using Fixed and Time-Varying Trade Weights

Country	Fixed Weights	Time-Varying Weights
	Residuals	Residuals
United States	-0.04	-0.04
Euro area	-0.01	-0.02
China	-0.02	0.01
Japan	-0.08	-0.09
United Kingdom	-0.00	-0.00
Sweden	0.02	0.02
Switzerland	0.02	0.01
Norway	0.01	0.03

Table 27: Average Pair-Wise Cross Section Correlations of the Residuals for Inflation using Fixed and Time-Varying Trade Weights

Country	Fixed Weights	Time-Varying Weights
	Residuals	Residuals
United States	0.02	0.04
Euro area	-0.01	0.05
China	-0.05	-0.00
Japan	0.01	0.03
United Kingdom	0.01	0.03
Sweden	0.00	0.06
Switzerland	0.04	0.03
Norway	0.04	0.05

Table 28: Average Pair-Wise Cross Section Correlations of the Residuals for Real Equity Prices using Fixed and Time-Varying Trade Weights

Country	Fixed Weights	Time-Varying Weights
	Residuals	Residuals
United States	-0.02	-0.01
Euro area	-0.08	-0.09
Japan	-0.08	-0.08
United Kingdom	-0.03	-0.03
Sweden	-0.04	-0.04
Switzerland	-0.05	-0.04
Norway	0.01	0.00

Table 29: Average Pair-Wise Cross Section Correlations of the Residuals for Real Exchange Rates using Fixed and Time-Varying Trade Weights

Country	Fixed Weights	Time-Varying Weights
	Residuals	Residuals
Euro area	0.27	0.27
China	0.02	0.01
Japan	0.17	0.17
United Kingdom	0.18	0.18
Sweden	0.21	0.18
Switzerland	0.26	0.26
Norway	0.26	0.26

Table 30: Average Pair-Wise Cross Section Correlations of the Residuals for the Short-Term Interest Rates using Fixed and Time-Varying Trade Weights

Country	Fixed Weights	Time-Varying Weights
	Residuals	Residuals
United States	0.02	0.02
Euro area	0.04	0.04
China	-0.05	-0.03
Japan	-0.00	-0.00
United Kingdom	0.01	0.01
Sweden	0.00	-0.01
Switzerland	-0.02	-0.02
Norway	-0.00	0.00

Table 31: Average Pair-Wise Cross Section Correlations of the Residuals for the Long-Term Interest Rates using Fixed and Time-Varying Trade Weights

Country	Fixed weights	Time-Varying Weights
	Residuals	Residuals
United States	-0.03	-0.03
Euro area	-0.05	-0.06
Japan	-0.05	-0.04
United Kingdom	-0.02	-0.03
Sweden	0.07	0.06
Switzerland	0.02	0.02
Norway	0.02	-0.00

Figure 1: Structural impulse responses of a positive unit (+1 σ) shock to oil prices

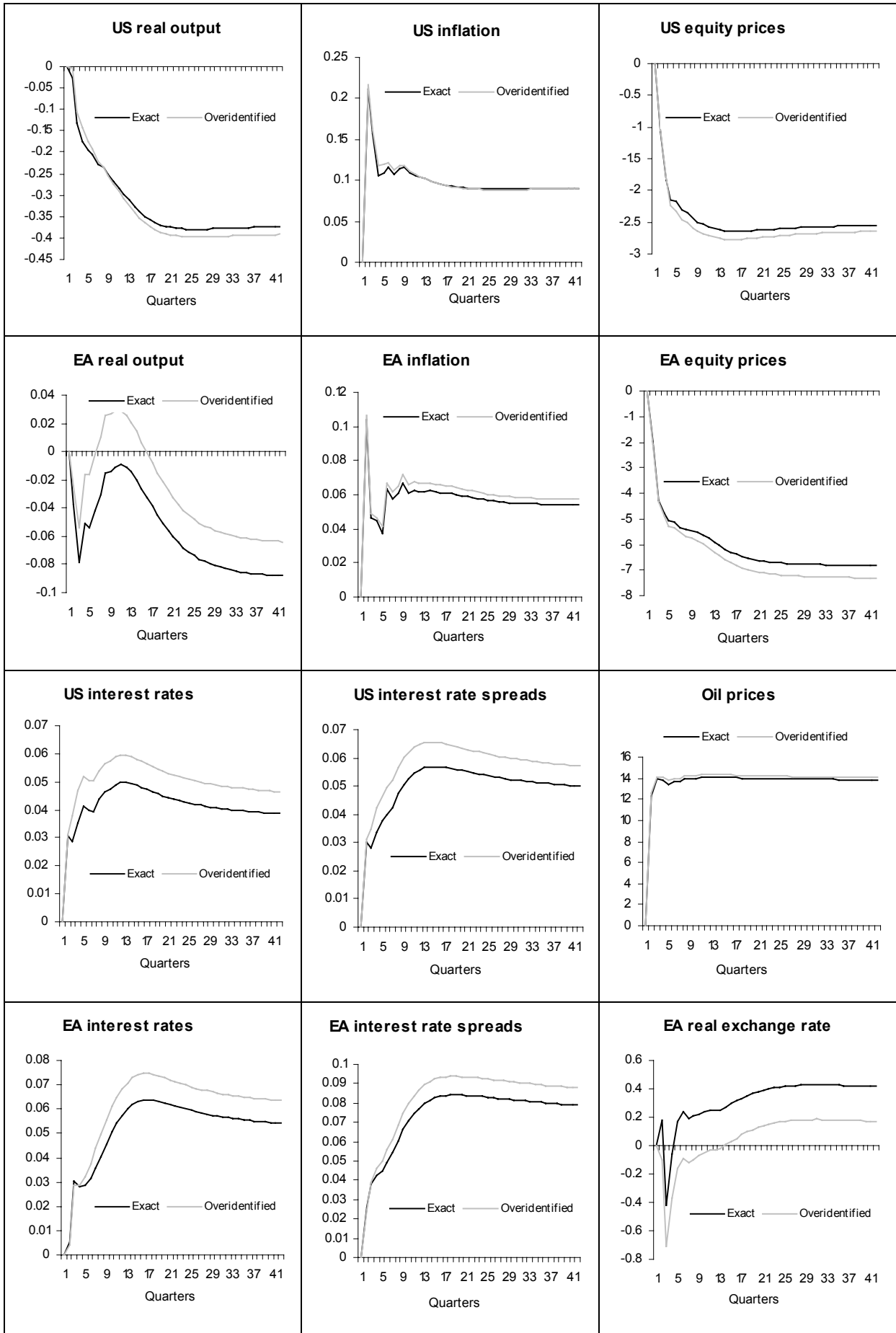


Figure 2: Structural and non structural impulse responses of a negative unit ($-\sigma$) shock to US equity prices

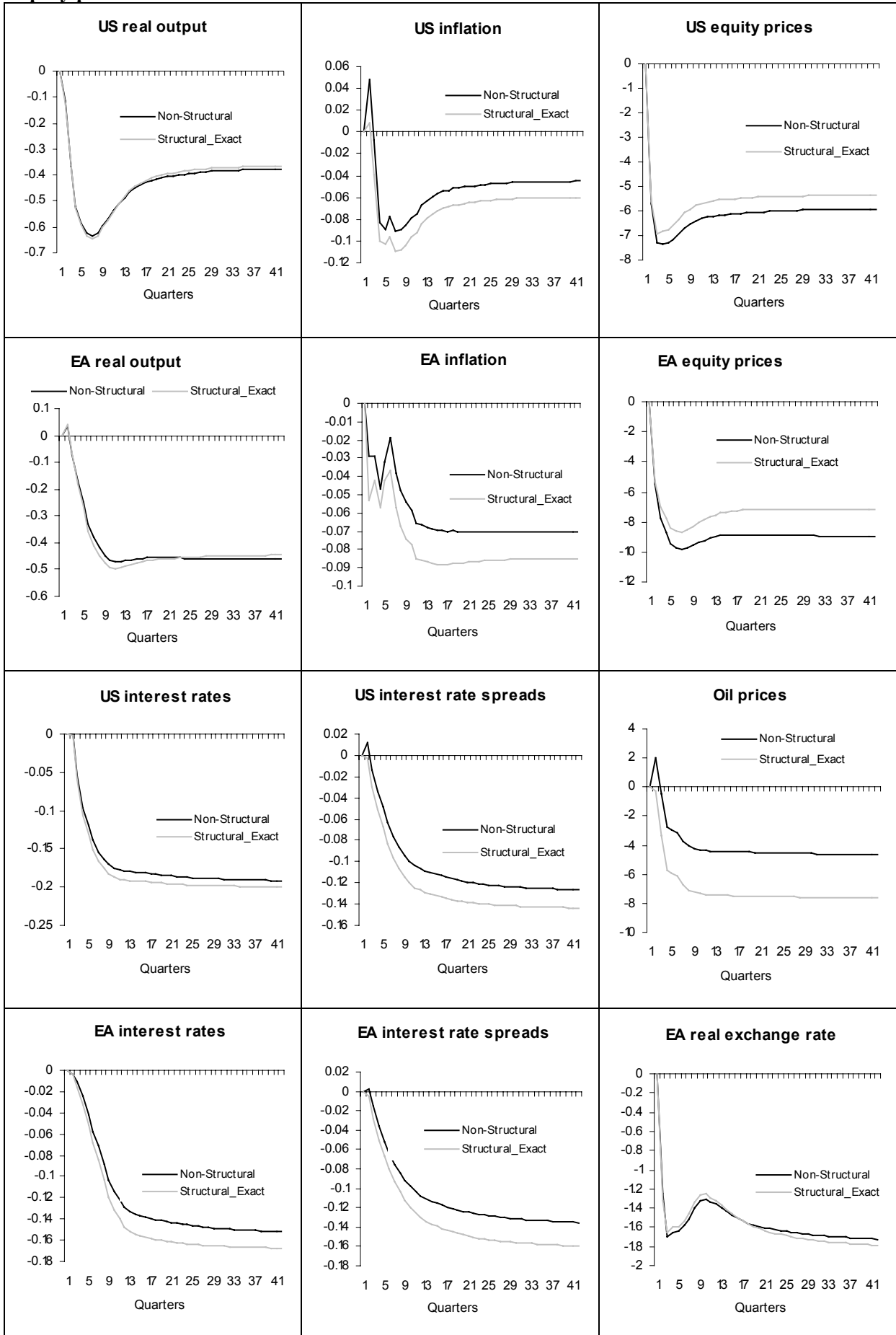


Figure 3: Structural impulse responses of a negative unit (-1σ) shock to US equity prices

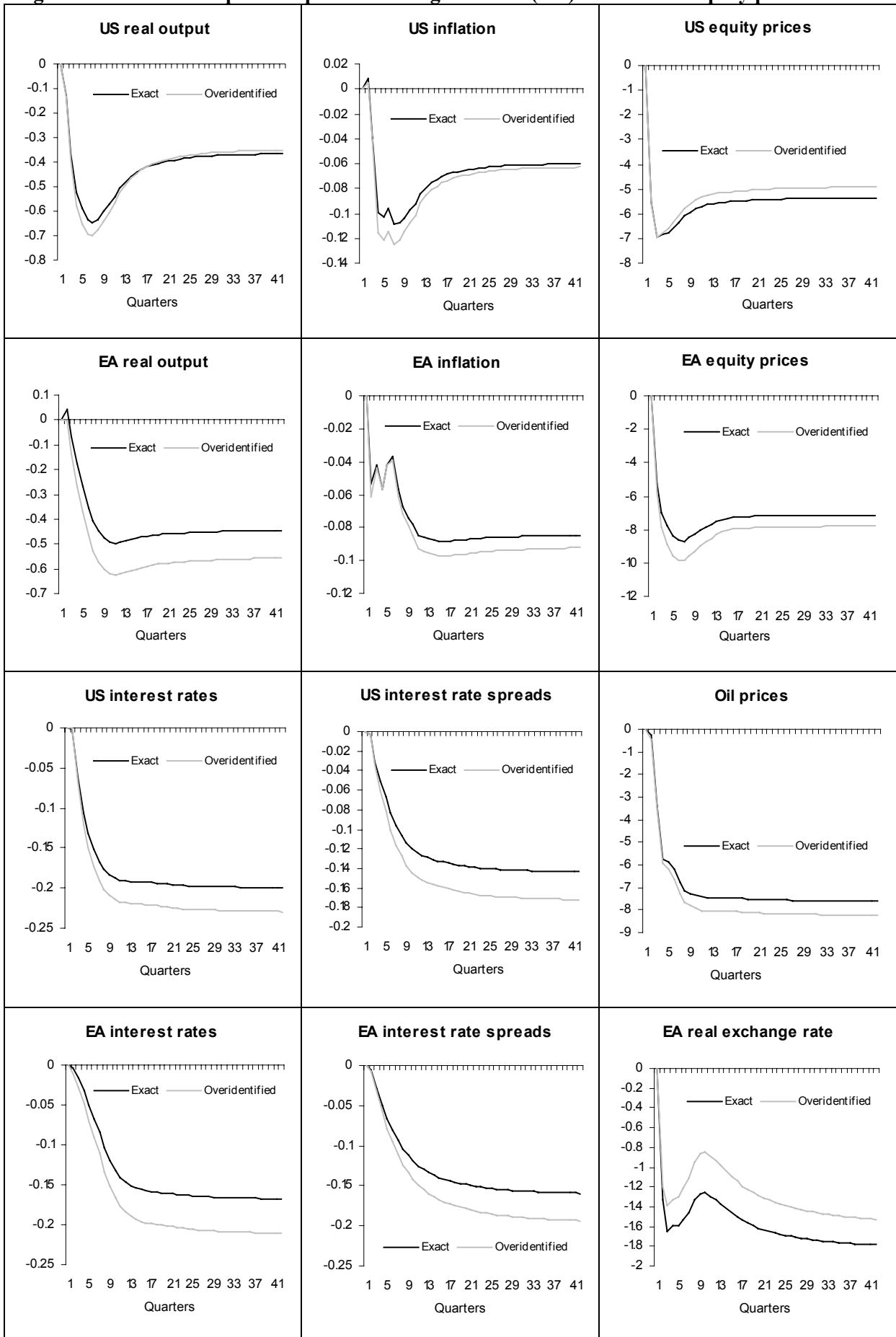


Figure 4: Structural and non structural impulse responses of a negative unit ($-\sigma$) shock to US real GDP

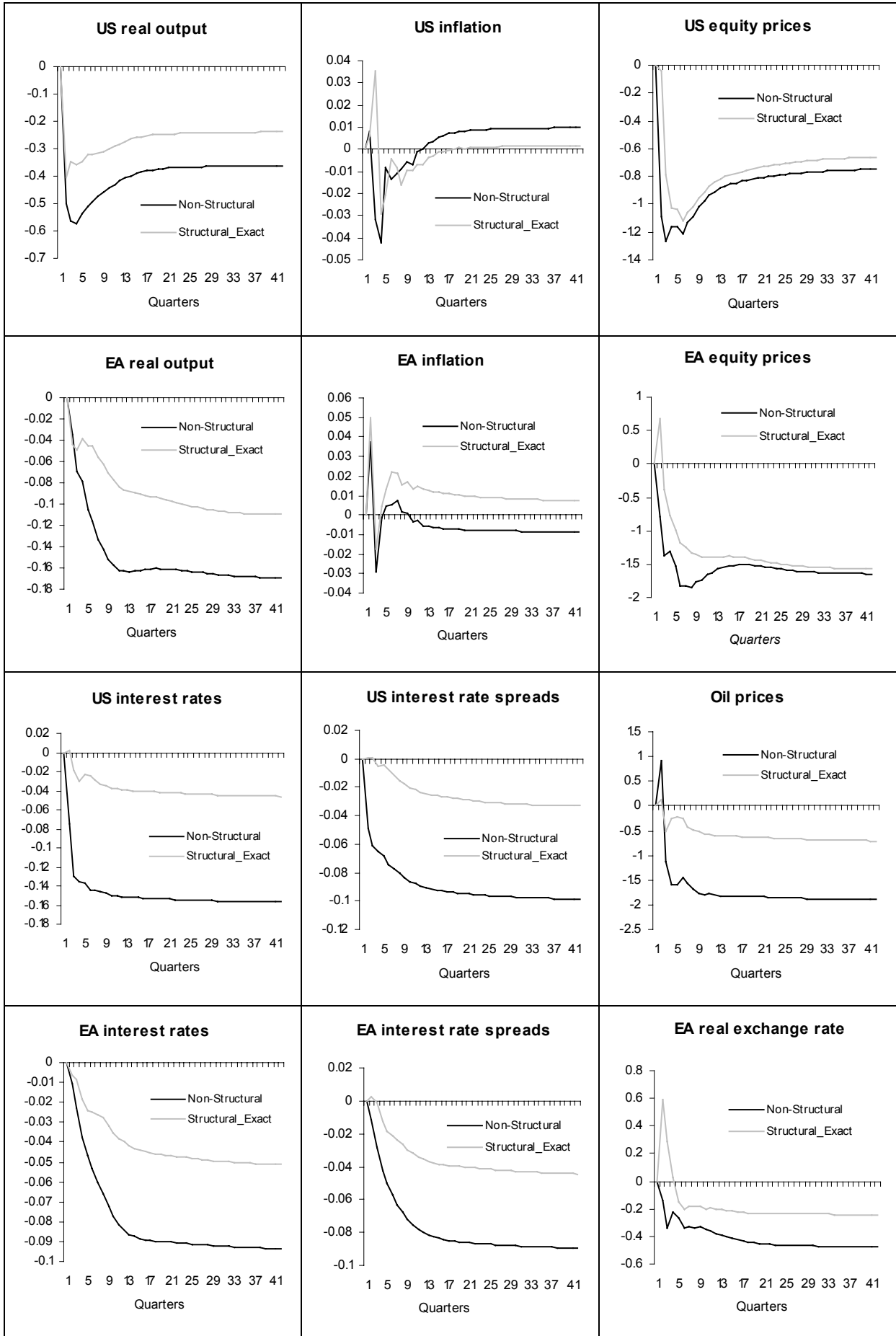


Figure 5: Structural impulse responses of a negative unit (-1σ) shock to US real output

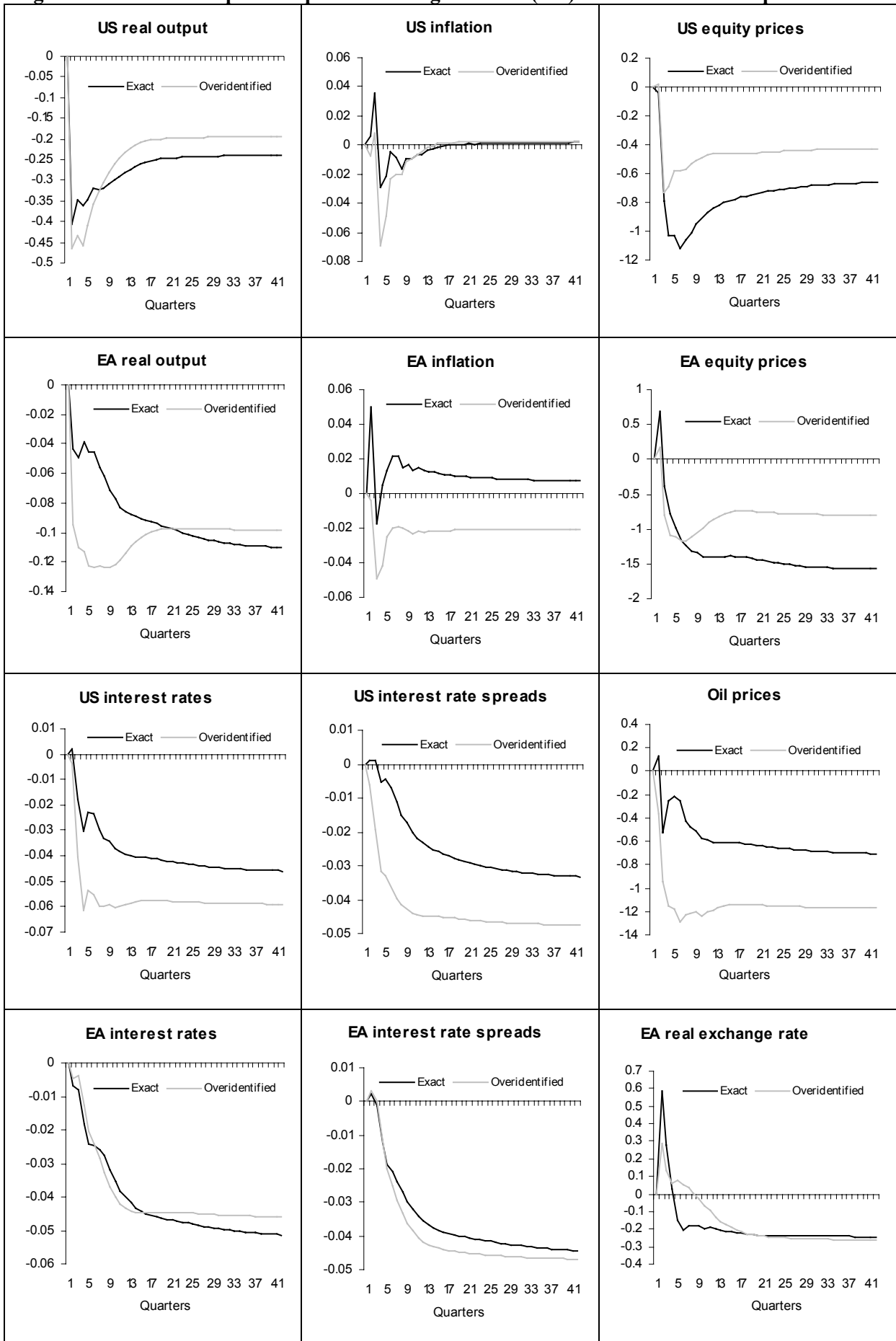


Figure 6: Structural and non structural impulse responses of a positive unit ($+1\sigma$) shock to US interest rates

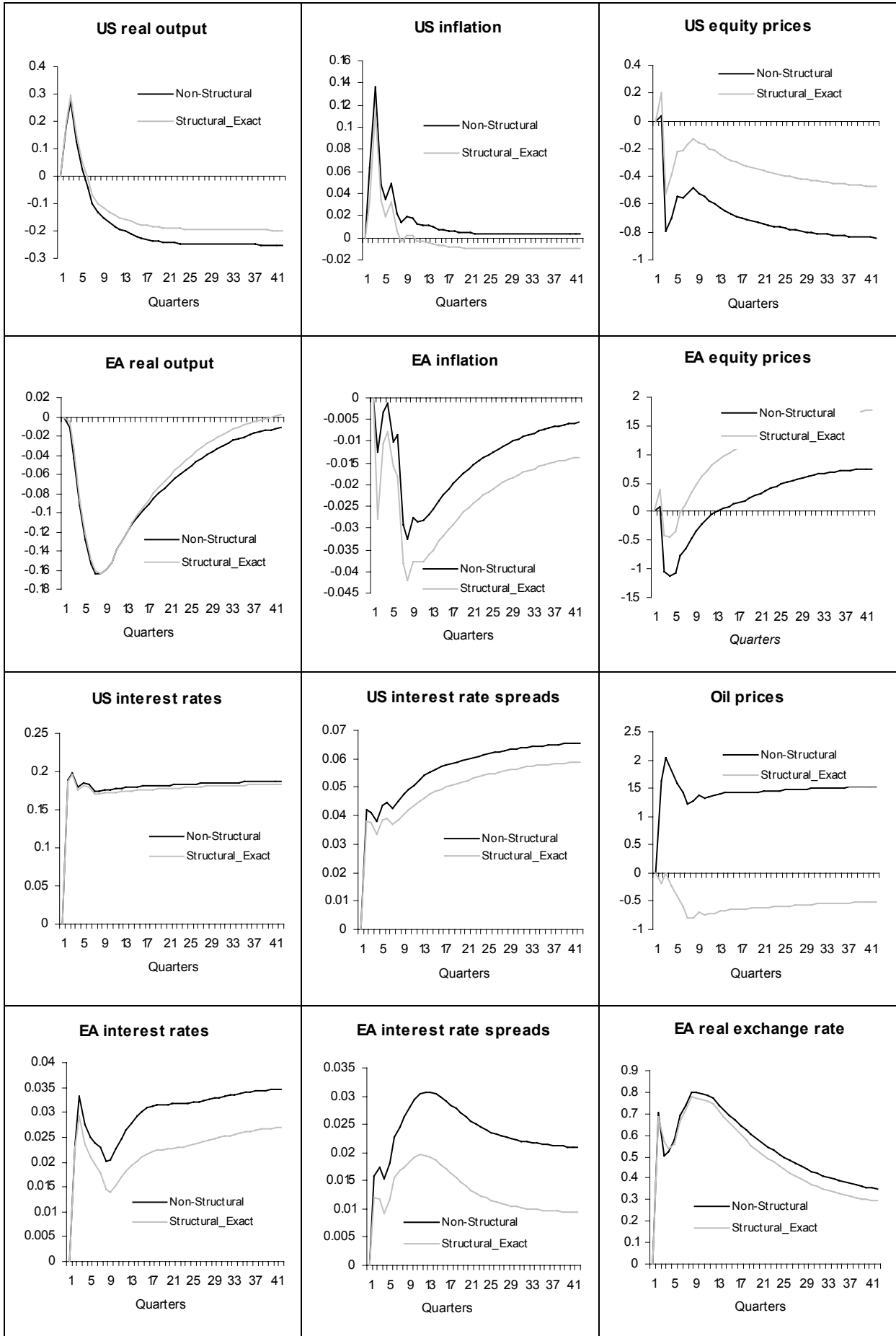


Figure 7: Structural impulse responses of a positive unit (+1 σ) shock to US interest rates

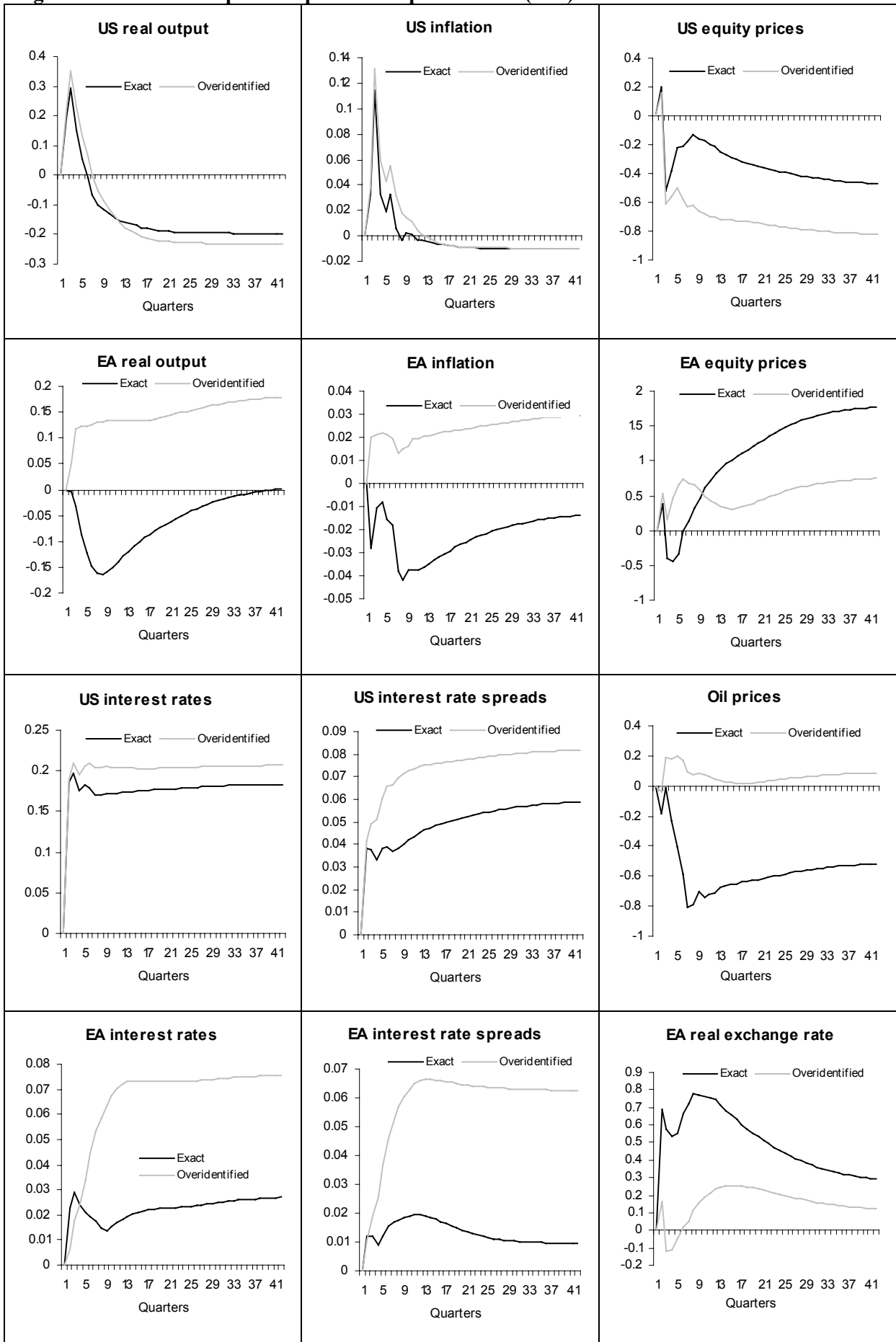
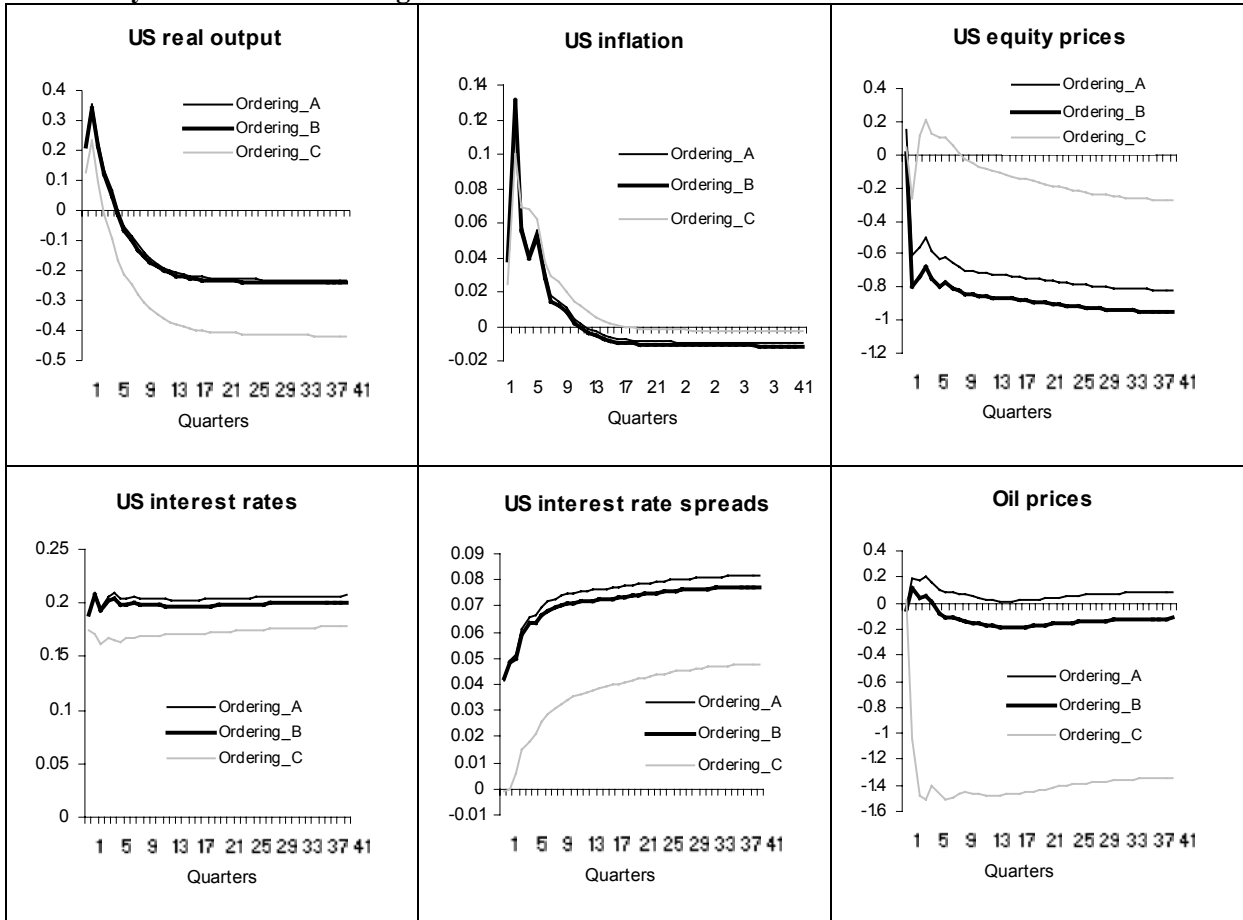


Figure 8: Structural impulse responses of a positive unit (+1 σ) shock to US monetary shock – sensitivity to different orderings



APPENDIX A: DATA

The variables used in this paper are:

Y :	Real GDP
CPI :	Consumer price index
EQ :	Equity price index
E :	Exchange rate
R^S :	Short-term interest rate
R^L :	Long-term interest rate
P^o :	Oil price

A.1. Output (real GDP)

The source of all 33 countries is the IMF's International Financial Statistics (IFS) GDP series in 1995 constant prices, except Australia (2001/02), Norway (2001), Singapore (2000), United Kingdom (2000) and United States (2000). France, Germany, Italy, Japan, South Africa, Spain, Netherlands, Switzerland, Australia, New Zealand, Mexico, United Kingdom and United States are all from series br, and the remaining countries are from series bp. Where recent data were not available, the IFS series were completed with growth rates derived from series provided by Global Insight.

Where quarterly data were not available (i.e. for Argentina, Belgium, Brazil, Chile, China India, indonesia, Malaysia, Mexico, Philipines, Saudi Arabia, Thailand and Turkey), quarterly series were interpolated linearly from the annual series (see A.7). Interpolated series were used only during the periods 1981-1992 for Argentina, 1979 for Belgium, 1979-1989 for Brazil, 1979 for Chile, 1979-1996 for India, 1979-1982 for Indonesia, 1979-1987 for Malaysia, 1979 for Mexico, 1979-1980 for the Philipines, 1979-1992 for Thailand and 1979-1986 for Turkey. Quarterly output series were avialble for the subsequent periods.

The data for Singapore are from Datastream.

For the period before the German unification, in 1990Q4, West German growth rates were used.

The data for Argentina, Austria, Belgium, Brazil, Chile, Finland, India, Indonesia, Korea, Malaysia, Norway, Peru, Philippines, Sweden, Thailand and Turkey were seasonally adjusted. Seasonal adjustment was performed with Eviews, using the U.S. Census Bureau's X12 program (for further details, see U.S. Census Bureau, 2000).

A.2. Consumer price indices

The data source for all countries was the IFS Consumer Price Index series 64 zf, except China (64 xzf).

A.3. Equity Price Indices

The data source was the IFS series 62 zf (Industrial share prices) for 25 countries (Australia, Austria, Brazil, Canada, Chile, Finland, France, Germany, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Peru,

Philippines, Saudi Arabia, South Africa, Spain, Sweden, Switzerland, Thailand, United Kingdom, United States). For Norway, Sweden, France, United Kingdom, the IFS data were completed with OECD Main Economic Indicator database (MEI) the IFS data for Austria were completed with Datastream series.

The data source for Belgium, Brazil and Switzerland was Datastream.

The data source for Malaysia, Turkey and China was Bloomberg.

A.4. Exchange Rates

IFS series rf was used for all countries.

A.5. Short-Term Interest Rates

The data source was the IFS series 60 b (Money market - interbank - rate) for 16 countries. For the 8 Euro Area countries (Austria, Belgium, France, Finland, Germany, Italy, Netherlands, and Spain) the ST interest rate was constructed as follows: for 1979Q1-1998Q4, the short-term country-specific inter-bank rate from IFS was used. From 99Q1-01Q4, the overnight EONIA rate was used as the common short-term interest rate for all 8 countries. IFS deposit rate series 60l were used for Argentina, Chile, Saudi Arabia and Turkey. The IFS Treasury Bill rate series 60c were used for Mexico and Philippines. For Sweden, some missing values at the end of the sample were replaced by the series 60 a (the two series are similar over the past). For China, New Zealand and Peru, IFS discount rate 60 were used. For India, Global Insight data were used to complete IFS series.

A.6. Long-Term Interest Rates

A long-term government bond rate was available from the IFS (series 61 zf) for 23 countries. Data from OECD were used to complete gaps in the IFS series for Austria and Sweden. Long-term interest rate series were not available for Argentina, Brazil, Chile, China, India, Indonesia, Peru, Saudi Arabia and Turkey.

A.7. Description of interpolation procedure

Let X_t , $t = 0, 1, 2, \dots, T$, be the annual observations compiled as averages of m time-disaggregated quarterly observations, x_{it} , $i = 1, 2, \dots, m$, $t = 1, 2, \dots, T$, such that

$$X_t = \sum_{i=1}^m x_{it} \quad (1)$$

The objective is to estimate a relatively smooth set of quarterly observations, x_{it} , $i = 1, 2, \dots, m$ that satisfy the above constraint. We confine ourselves to pure interpolation methods (namely without using any related economic time series) and assume that the underlying quarterly observations are generated by the following exact first-order autoregressive process.

For month t

$$\begin{aligned}
x_{t1} &= \rho_t x_{t-1,m} + \mu_t \\
x_{t2} &= \rho_t x_{t1,m} + \mu_t \\
x_{t2} &= \rho_t x_{t2,m} + \mu_t \\
&\vdots \\
x_{tm} &= \rho_t x_{t,m-1} + \mu_t.
\end{aligned}$$

For month $t + 1$

$$\begin{aligned}
x_{t+1,1} &= \rho_{t+1} x_{t,m} + \mu_{t+1} \\
x_{t+1,2} &= \rho_{t+1} x_{t+1,1} + \mu_{t+1} \\
x_{t+1,3} &= \rho_{t+1} x_{t+1,2} + \mu_{t+1} \\
&\vdots \\
x_{t+1,m} &= \rho_{t+1} x_{t+1,m-1} + \mu_{t+1}
\end{aligned}$$

and similarly for subsequent time periods.

The above interpolations depend on the intercept coefficient, μ_{t+1} (which is assumed to vary from one year to the next) and the autoregressive coefficient, ρ_{t+1} . Solving for $x_{t+1,i}$ recursively forward we have

$$x_{t+1,i} = \rho_{t+1}^i x_{tm} + \mu_{t+1} \frac{(1 - \rho_{t+1}^i)}{(1 - \rho_{t+1})}, \text{ for } i = 1, 2, \dots, m. \quad (2)$$

Substituting these in the constraint, (1) we find

$$X_t = \rho_{t+1} \frac{(1 - \rho_{t+1}^m)}{(1 - \rho_{t+1})} x_{tm} + \frac{m \mu_{t+1}}{1 - \rho_{t+1}} - \rho_{t+1} \frac{(1 - \rho_{t+1}^m)}{(1 - \rho_{t+1})^2} \mu_{t+1}.$$

It is easily verified that the quarterly interpolations, $x_{t+1,i}$, do in fact exactly add up to the annual data, X_{t+1} .

The uniformly distributed interpolated series, $x_{t+1,i} = X_{t+1}/m$, for $i = 1, 2, \dots, m$, correspond to the case where $\rho_{t+1} = 0$. We adopt the geometrically (exponentially) interpolated series which is obtained by setting $\mu_{t+1} = 0$, while other intermediate cases can also be entertained.

For the exponential interpolation, ρ_{t+1} is computed as the solution to

$$X_{t+1} = \rho_{t+1} \frac{(1 - \rho_{t+1}^m)}{(1 - \rho_{t+1})} x_{tm}, \quad (3)$$

where x_{tm} is the observation at the end of the previous year. This formulation is suitable when interpolating the level of the variables (indices) rather than the growth rates and is applicable to I(1) variables.

To solve for ρ_{t+1} , let $\lambda_{t+1,m} = X_{t+1}/x_{tm}$, and write (3) in the expanded form

$$\rho_{t+1}^m + \rho_{t+1}^{m-1} + \dots + \rho_{t+1} = \lambda_{t+1,m}, \text{ for } t = 0, 1, \dots, \quad (4)$$

with

$$\lambda_{1,m} = X_1/x_{0m} = m(X_1/X_0). \quad (5)$$

It follows that

$$x_{t+1,i} = x_{tm}\rho_{t+1}^i, \quad t = 0, 1, \dots; i = 1, 2, \dots, m. \quad (6)$$

To proceed it is required to solve the m th order polynomial equation given by (4). For the purpose of our empirical application we are interested in interpolating quarterly observations from annual series, which implies solving the quartic equation

$$\rho_{t+1}^4 + \rho_{t+1}^3 + \dots + \rho_{t+1} - \lambda_{t+1,4} = 0. \quad (7)$$

To solve the quartic equation of the general form

$$A_4z^4 + A_3z^3 + A_2z^2 + A_1z + A_0 = 0$$

or

$$z^4 + a_3z^3 + a_2z^2 + a_1z + a_0 = 0 \quad (8)$$

with $a_i = A_i/A_4$, $i = 0, 1, 2, 3$, we substitute $z = x - a_3/4$ in (8) which yields

$$x^4 + px^2 + qx + r = 0, \quad (9)$$

where

$$\begin{aligned} p &= a_2 - \frac{3}{8}a_3^2 \\ q &= a_1 - \frac{1}{2}a_2a_3 + \frac{1}{8}a_3^3 \\ r &= a_0 - \frac{1}{4}a_1a_3 + \frac{1}{16}a_2a_3^2 - \frac{3}{256}a_3^4. \end{aligned}$$

In order to solve equation (9) it needs to be made factorable, which leads to the solution of the following cubic equation

$$u^3 + b_2u^2 + b_1u + b_0 = 0, \quad (10)$$

where

$$\begin{aligned} b_2 &= -p \\ b_1 &= -4r \\ b_0 &= 4pr - q^2. \end{aligned}$$

The cubic equation (10) has only one real root if the discriminant D is greater than zero, where D is defined by

$$D = Q^3 + R^2$$

and

$$Q = \frac{3b_1 - b_2^2}{9}$$

$$R = \frac{9b_1b_2 - 27b_0 - 2b_2^3}{54}.$$

In this case, $D > 0$, the unique real root is given by

$$u_1 = (R + \sqrt{D})^{1/3} - \frac{Q}{(R + \sqrt{D})^{1/3}} - \frac{1}{3}.$$

Then, by using the above solution to the cubic polynomial, u_1 , the following quadratic equations arise

$$x^2 + \sqrt{u_1 - px} + \frac{1}{2}u_1 - \frac{q}{2\sqrt{u_1 - p}} = 0 \quad (11a)$$

$$x^2 - \sqrt{u_1 - px} + \frac{1}{2}u_1 + \frac{q}{2\sqrt{u_1 - p}} = 0, \quad (11b)$$

If x_r is a real solution of the pair of quadratics (11) then $x_r - a_3/4$ is a real solution to the quartic equation (8). Thus a real solution to (7) is given by

$$\rho_{t+1} = x_{r,t+1} - 1/4$$

However, multiple real solutions can arise from the solution of the quartic equation defined in (8). Consider, two real solutions, a and b . Let $\{y_{i1}^a, y_{i2}^a, y_{i3}^a, y_{i4}^a, \dots\}$ and $\{y_{i1}^b, y_{i2}^b, y_{i3}^b, y_{i4}^b, \dots\}$ be the levels of the interpolated series based on the choice of the roots a and b , respectively.

In this case, we define

$$\Delta_a = \frac{|\ln(y_{i1}^a/y_{i1-1,4}^a)| + |\ln(y_{i21}^a/y_{i1}^a)| + |\ln(y_{i41}^a/y_{i3}^a)| + \dots}{4}$$

$$\Delta_b = \frac{|\ln(y_{i1}^b/y_{i1-1,4}^b)| + |\ln(y_{i21}^b/y_{i1}^b)| + |\ln(y_{i41}^b/y_{i3}^b)| + \dots}{4}$$

and choose a if $\Delta_a < \Delta_b$, b otherwise.

APPENDIX B: Detailed Results

Table B1: Trade Weights Based on Direction of Trade Statistics

Country	China	Euro area	Japan	Argent.	Brazil	Chile	Mexico	Peru	Austr.	Canada	New Z.	Indon.	Korea	Malays.	Philip.	Singap.	Thail.	India	S. Afric.	S. Arab.
China	0	0.1635	0.2503	0.0047	0.0089	0.0058	0.0057	0.0019	0.0251	0.0201	0.0032	0.0201	0.1007	0.0240	0.0095	0.0320	0.0190	0.0090	0.0063	0.0095
Euro area	0.0565	0	0.0725	0.0079	0.0232	0.0051	0.0129	0.0015	0.0121	0.0192	0.0025	0.0091	0.0206	0.0132	0.0068	0.0164	0.0111	0.0140	0.0142	0.0144
Japan	0.1278	0.1319	0	0.0018	0.0081	0.0050	0.0105	0.0011	0.0354	0.0241	0.0053	0.0333	0.0705	0.0394	0.0245	0.0367	0.0354	0.0074	0.0070	0.0238
Argentina	0.0460	0.2157	0.0337	0	0.2953	0.0744	0.0212	0.0080	0.0033	0.0124	0.0013	0.0041	0.0183	0.0103	0.0018	0.0030	0.0086	0.0141	0.0095	0.0014
Brazil	0.0271	0.2593	0.0587	0.1362	0	0.0230	0.0252	0.0058	0.0063	0.0179	0.0007	0.0048	0.0232	0.0063	0.0022	0.0056	0.0045	0.0091	0.0063	0.0140
Chile	0.0570	0.1881	0.1035	0.1143	0.0728	0	0.0464	0.0230	0.0048	0.0235	0.0015	0.0058	0.0409	0.0048	0.0031	0.0020	0.0041	0.0062	0.0031	0.0035
Mexico	0.0108	0.0516	0.0251	0.0019	0.0074	0.0042	0	0.0012	0.0014	0.0222	0.0007	0.0015	0.0128	0.0052	0.0021	0.0036	0.0020	0.0013	0.0006	0.0007
Peru	0.0424	0.1734	0.0573	0.0221	0.0441	0.0676	0.0305	0	0.0054	0.0239	0.0040	0.0039	0.0282	0.0022	0.0028	0.0014	0.0062	0.0058	0.0017	0.0002
Australia	0.0802	0.1192	0.1928	0.0011	0.0053	0.0012	0.0045	0.0005	0	0.0178	0.0606	0.0314	0.0664	0.0337	0.0098	0.0495	0.0245	0.0142	0.0105	0.0148
Canada	0.0213	0.0462	0.0348	0.0008	0.0035	0.0013	0.0193	0.0005	0.0036	0	0.0010	0.0021	0.0095	0.0038	0.0022	0.0024	0.0030	0.0024	0.0010	0.0015
New Z.	0.0546	0.1186	0.1407	0.0025	0.0029	0.0016	0.0093	0.0018	0.2478	0.0178	0	0.0145	0.0375	0.0269	0.0095	0.0200	0.0155	0.0068	0.0039	0.0149
Indonesia	0.0554	0.1260	0.2331	0.0020	0.0062	0.0023	0.0034	0.0008	0.0450	0.0118	0.0042	0	0.0781	0.0359	0.0119	0.1207	0.0272	0.0202	0.0037	0.0244
Korea	0.1228	0.1044	0.1950	0.0028	0.0108	0.0058	0.0108	0.0013	0.0336	0.0170	0.0041	0.0332	0	0.0316	0.0199	0.0341	0.0142	0.0100	0.0062	0.0392
Malaysia	0.0435	0.1034	0.1884	0.0022	0.0028	0.0011	0.0046	0.0002	0.0264	0.0072	0.0044	0.0255	0.0443	0	0.0232	0.1827	0.0432	0.0179	0.0033	0.0060
Philippines	0.0293	0.1285	0.2054	0.0010	0.0025	0.0013	0.0040	0.0006	0.0182	0.0098	0.0036	0.0159	0.0628	0.0429	0	0.0829	0.0365	0.0044	0.0013	0.0174
Singapore	0.0558	0.1076	0.1387	0.0005	0.0026	0.0005	0.0058	0.0001	0.0254	0.0043	0.0028	0.0424	0.0419	0.2022	0.0293	0	0.0523	0.0178	0.0028	0.0206
Thailand	0.0585	0.1261	0.2389	0.0036	0.0041	0.0013	0.0051	0.0010	0.0267	0.0113	0.0038	0.0255	0.0324	0.0568	0.0212	0.0876	0	0.0108	0.0058	0.0142
India	0.0420	0.2471	0.0670	0.0083	0.0093	0.0028	0.0059	0.0010	0.0267	0.0172	0.0025	0.0228	0.0317	0.0372	0.0040	0.0469	0.0150	0	0.0242	0.0421
S. Africa	0.0359	0.3545	0.0863	0.0077	0.0166	0.0017	0.0045	0.0005	0.0294	0.0111	0.0022	0.0080	0.0282	0.0119	0.0023	0.0110	0.0120	0.0177	0	0.0482
S. Arabia	0.0314	0.1925	0.1722	0.0008	0.0162	0.0006	0.0027	0.0000	0.0194	0.0094	0.0039	0.0204	0.1026	0.0097	0.0110	0.0474	0.0157	0.0295	0.0219	0
Turkey	0.0229	0.5784	0.0309	0.0022	0.0059	0.0016	0.0017	0.0005	0.0060	0.0069	0.0006	0.0045	0.0204	0.0055	0.0009	0.0049	0.0039	0.0085	0.0056	0.0231
Norway	0.0197	0.4491	0.0300	0.0007	0.0058	0.0010	0.0016	0.0007	0.0025	0.0465	0.0004	0.0014	0.0114	0.0016	0.0007	0.0047	0.0024	0.0021	0.0011	0.0006
Sweden	0.0243	0.5139	0.0352	0.0022	0.0081	0.0026	0.0066	0.0005	0.0084	0.0097	0.0013	0.0028	0.0071	0.0061	0.0015	0.0052	0.0045	0.0041	0.0033	0.0057
Switz.	0.0151	0.6699	0.0390	0.0020	0.0081	0.0010	0.0050	0.0004	0.0055	0.0077	0.0010	0.0018	0.0063	0.0034	0.0017	0.0077	0.0057	0.0051	0.0046	0.0047
UK	0.0198	0.5372	0.0424	0.0015	0.0061	0.0017	0.0039	0.0006	0.0126	0.0214	0.0028	0.0048	0.0136	0.0099	0.0046	0.0126	0.0067	0.0109	0.0120	0.0080
USA	0.0734	0.1553	0.1243	0.0048	0.0180	0.0043	0.1412	0.0023	0.0113	0.2408	0.0026	0.0082	0.0379	0.0209	0.0130	0.0220	0.0137	0.0088	0.0044	0.0123

Note: Trade weights are computed as shares of exports and imports, displayed in rows by region (such that a row, but not a col)
 Source: Direction of Trade Statistics, 1999-2001, IMF.

Table B2: ADF Unit Root Test Statistics for Domestic Variables (Based on AIC Order Selection)

Variable	China	Euro area	Japan	Argentina	Brazil	Chile	Mexico	Peru	Australia	Canada	New Z.	Indon.	Korea	Malaysia	Philippines	Singapore	Thailand	India	S. Africa	S. Arabia
y	-3.75	-2.44	-1.35	-2.89	-2.53	-2.51	-3.26	-2.48	-2.12	-2.41	-1.56	-1.38	-1.60	-2.34	-2.66	-1.88	-1.92	-5.32	-2.39	-1.35
Dy	-3.34	-4.60	-3.46	-5.01	-6.87	-3.78	-3.60	-8.38	-6.60	-4.49	-8.21	-9.33	-5.07	-4.54	-3.13	-7.25	-2.57	-8.23	-5.53	-2.95
D²y	-9.90	-8.12	-14.30	-6.97	-7.89	-12.04	-18.55	-9.11	-7.30	-10.54	-7.60	-7.43	-6.93	-7.30	-10.56	-7.88	-8.92	-7.70	-7.21	-14.40
p	-3.61	-2.01	-0.60	-1.57	-1.92	0.51	-1.12	-1.61	-0.40	0.79	0.05	-1.91	-2.70	-2.53	-0.85	-1.30	-2.32	-1.01	0.73	-1.82
Dp	-3.16	0.28	-0.54	-2.45	-2.35	-2.53	-2.79	-2.92	-2.01	-1.31	-2.25	-4.79	-1.52	-2.27	-4.11	-2.62	-1.35	-3.66	-2.14	-8.14
D²p	-4.90	-11.15	-13.45	-11.06	-8.35	-8.97	-5.15	-13.28	-11.57	-9.20	-15.22	-7.90	-13.98	-11.72	-15.72	-8.05	-6.22	-13.99	-11.60	-8.40
q	-	-3.05	-1.46	-4.21	-	-2.10	-	-	-2.89	-3.50	-2.52	-	-2.07	-2.41	-2.20	-3.13	-2.02	-2.39	-4.40	-
Dq	-	-4.26	-6.79	-6.30	-	-7.44	-	-	-9.36	-6.23	-9.29	-	-7.01	-10.42	-5.11	-9.81	-3.46	-5.83	-7.31	-
D²q	-	-12.43	-6.83	-7.28	-	-6.90	-	-	-8.21	-6.89	-9.46	-	-10.48	-13.55	-7.36	-10.39	-13.07	-7.30	-7.80	-
e	-0.88	-2.45	-2.43	-1.34	-1.29	-0.69	-1.63	-1.15	-2.53	-2.67	-1.57	-2.58	-2.52	-2.81	-2.17	-1.23	-2.38	-1.49	-3.50	-0.74
De	-9.08	-7.17	-4.25	-3.15	-2.77	-5.54	-3.01	-4.92	-7.44	-2.35	-4.79	-6.56	-4.96	-6.75	-6.54	-9.33	-7.01	-6.84	-3.79	-4.11
D²e	-8.46	-8.90	-9.09	-12.00	-8.38	-8.73	-11.00	-7.80	-7.82	-14.41	-7.84	-8.07	-7.17	-8.03	-6.54	-9.03	-7.29	-7.77	-14.21	-6.85
r	-1.20	-1.26	-1.61	-2.16	-3.43	-1.09	-1.70	-3.02	-2.30	-1.36	-2.10	-3.96	-1.40	-3.16	-2.77	-1.12	-1.99	-3.54	-3.09	-
Dr	-7.68	-5.51	-5.65	-14.28	-8.26	-8.69	-5.64	-4.02	-8.00	-13.50	-7.53	-5.75	-8.26	-5.62	-8.65	-6.04	-9.57	-5.05	-4.75	-
D²r	-7.17	-9.34	-7.79	-11.59	-10.19	-7.64	-9.81	-8.02	-10.21	-7.82	-8.57	-10.80	-8.51	-8.68	-8.75	-8.97	-7.05	-9.40	-16.61	-
lr	-	-2.71	-1.95	-	-	-	-	-	-1.65	-3.36	-1.42	-	-2.75	-	-	-	-	-	-1.27	-
Dlr	-	-4.58	-8.87	-	-	-	-	-	-8.38	-5.30	-6.34	-	-8.25	-	-	-	-	-	-8.32	-
D²lr	-	-7.59	-9.88	-	-	-	-	-	-8.02	-7.79	-7.83	-	-8.36	-	-	-	-	-	-7.54	-
oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Doil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D²oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
e-p	-2.22	-2.09	-2.09	-1.95	-2.23	-2.26	-3.68	-1.44	-2.78	-1.91	-2.52	-2.83	-2.21	-2.49	-1.91	-0.98	-1.94	-1.70	-2.95	-1.62
D(e-p)	-4.02	-7.48	-8.11	-9.77	-8.91	-5.94	-8.73	-8.08	-7.51	-2.19	-4.77	-7.11	-4.95	-6.72	-7.74	-8.27	-6.53	-7.47	-3.97	-7.18
D²(e-p)	-13.00	-8.96	-9.60	-8.29	-8.07	-9.24	-12.60	-7.72	-7.93	-14.45	-7.80	-8.62	-7.15	-8.19	-6.72	-8.60	-7.32	-7.78	-9.43	-8.09

Note: The WS statistics for all level variables are based on regressions including a linear trend, except for the interest rate variable. The WS statistics for regressions with trend is -3.24, and for regressions without trend -2.55.

Table B3: ADF Unit Root Test Statistics for Foreign Variables (Based on AIC Order Selection)

Variable	China	Euro area	Japan	Argentina	Brazil	Chile	Mexico	Peru	Australia	Canada	New Z.	Indon.	Korea	Malaysia	Philippines	Singapore	Thailand	India	S. Africa	S. Arab
y*	-1.67	-2.72	-2.45	-2.36	-2.89	-2.50	-2.83	-2.93	-1.94	-2.92	-2.41	-1.67	-2.30	-1.69	-1.88	-2.09	-1.89	-2.58	-2.36	-1.69
Dy*	-5.84	-4.75	-5.66	-5.49	-5.07	-5.23	-6.61	-4.76	-5.45	-6.91	-5.61	-5.48	-5.28	-5.54	-5.30	-5.31	-5.43	-5.09	-5.44	-5.97
D ² y*	-13.28	-6.72	-6.60	-7.69	-7.26	-7.22	-6.99	-6.97	-12.41	-7.13	-8.09	-6.75	-6.57	-6.80	-6.43	-7.01	-6.77	-6.88	-6.57	-7.06
p*	-0.62	-0.26	-0.79	-1.85	-1.37	-1.51	-0.38	-0.87	-0.93	0.01	-0.63	-1.21	-1.35	-0.63	-0.95	-0.30	-0.80	-0.81	-0.93	-0.85
Dp*	-0.56	-1.68	-0.94	-2.27	-2.20	-2.69	-0.40	-2.04	-0.36	-0.03	0.09	-0.65	-1.10	-0.03	0.50	-0.84	-0.10	-0.86	-1.28	-0.97
D ² p*	-11.47	-5.26	-4.35	-8.20	-11.02	-15.90	-12.67	-12.65	-6.13	-14.05	-10.23	-5.94	-6.03	-9.13	-9.87	-8.47	-9.96	-11.47	-10.29	-10.92
q*	-2.11	-2.32	-2.38	-2.12	-2.60	-2.37	-2.17	-2.26	-2.30	-2.14	-2.33	-2.35	-2.29	-2.44	-2.36	-2.10	-2.45	-2.75	-2.57	-2.19
Dq*	-6.54	-6.98	-7.28	-7.33	-5.47	-5.54	-7.43	-7.00	-6.68	-7.42	-7.52	-5.27	-6.67	-6.50	-6.31	-8.13	-5.26	-6.61	-7.03	-6.65
D ² q*	-10.91	-11.18	-11.00	-8.85	-7.21	-7.29	-8.56	-11.13	-10.97	-8.65	-11.14	-10.95	-10.90	-11.07	-11.03	-11.39	-10.83	-11.63	-11.90	-11.07
e*	-2.17	-0.87	-1.26	-0.71	-1.12	-1.16	-0.63	-0.07	-2.19	-0.19	-1.81	-2.24	-1.88	-2.16	-2.11	-2.48	-2.27	-1.66	-1.58	-2.04
De*	-7.28	-6.86	-7.20	-3.97	-3.20	-2.58	-6.08	-5.26	-7.31	-7.59	-6.95	-7.42	-7.53	-7.72	-7.61	-7.23	-7.69	-7.36	-7.11	-7.12
D ² e*	-9.33	-7.16	-7.77	-8.24	-12.45	-11.02	-8.64	-8.51	-9.31	-10.48	-8.80	-9.36	-9.54	-9.41	-9.52	-8.98	-9.59	-9.51	-9.24	-9.26
r*	-1.26	-1.38	-1.01	-3.32	-1.85	-2.22	-1.21	-1.65	-0.65	-0.94	-1.53	-1.25	-0.86	-1.01	-0.91	-0.98	-1.52	-1.42	-1.16	-1.12
Dr*	-4.74	-9.63	-5.34	-8.17	-13.88	-5.68	-8.20	-10.09	-9.21	-3.52	-4.10	-4.63	-8.96	-4.53	-4.49	-8.07	-3.93	-4.80	-9.49	-9.46
D ² r*	-8.88	-9.60	-8.62	-10.18	-11.35	-9.18	-9.80	-9.40	-9.43	-10.09	-15.04	-8.61	-9.57	-15.15	-8.04	-12.46	-17.09	-8.47	-9.49	-9.93
lr*	-2.80	-3.88	-3.17	-2.62	-2.73	-2.72	-3.90	-3.78	-2.82	-3.89	-2.23	-2.77	-3.28	-2.80	-2.87	-2.77	-2.69	-2.63	-2.46	-2.76
Dlr*	-4.91	-5.50	-5.56	-5.19	-5.17	-5.23	-5.44	-5.18	-5.15	-7.52	-5.00	-4.67	-4.71	-4.92	-5.02	-5.08	-4.69	-5.25	-5.17	-5.18
D ² lr*	-7.33	-7.83	-7.57	-7.46	-7.52	-7.54	-7.15	-7.55	-7.68	-7.17	-7.38	-7.29	-7.68	-7.38	-7.33	-7.42	-7.43	-7.62	-7.60	-7.50
oil	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86	-2.86
Doil	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61	-5.61
D ² oil	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00	-8.00
(e-p)*	-1.62	-1.99	-1.93	-2.40	-1.87	-1.68	-0.36	-1.76	-1.88	0.52	-1.89	-1.70	-1.94	-1.57	-1.53	-1.93	-1.71	-1.84	-1.97	-1.74
D(e-p)*	-7.55	-7.34	-6.93	-8.71	-8.06	-7.98	-1.66	-6.84	-7.46	-2.23	-7.04	-7.62	-7.83	-7.77	-7.76	-7.27	-7.90	-7.52	-7.47	-7.35
D ² (e-p)*	-9.46	-7.46	-9.89	-8.91	-8.08	-8.12	-11.27	-9.25	-9.72	-8.90	-9.04	-9.68	-10.30	-9.65	-9.64	-7.08	-9.89	-9.46	-9.25	-9.48

Note: The WS statistics for all level variables are based on regressions including a linear trend, except for the interest rate variable. The WS statistics for regressions with trend is -3.24, and for regressions without trend -2.55.

Table B4: Cointegration Rank Statistics for Countries with 6 Exogenous Variables

H0	H1	Eur. area	Japan	Austral.	Canada	New Zeal.	Korea	S. Afric.	Norway	Sweden	Switz.	UK	Critical Values
													95%
Maximum Eigenvalue Statistics													
r=0	r=1	77.82	73.65	86.87	112.99	98.08	93.29	76.53	104.75	83.54	97.35	97.68	63.52
r=1	r=2	55.97	55.78	62.92	95.37	72.50	67.46	69.98	66.26	75.61	76.39	69.90	57.13
r=2	r=3	38.37	46.50	52.92	58.92	59.71	64.92	51.69	50.44	54.07	56.46	49.51	50.64
r=3	r=4	31.74	40.08	42.98	51.96	41.61	46.95	21.41	34.58	36.87	33.85	35.33	43.94
r=4	r=5	24.06	39.47	29.59	39.09	27.96	31.22	16.64	28.27	27.97	20.19	26.02	36.84
r=5	r=6	15.80	18.13	16.32	18.21	15.21	18.95	10.10	18.92	19.58	16.77	14.43	28.81
Trace Statistics													
r=0	r>1	243.76	273.61	291.60	376.55	315.08	322.79	246.34	303.22	297.64	301.01	292.87	197.7
r=1	r=2	165.94	199.96	204.73	263.56	217.00	229.50	169.81	198.48	214.10	203.66	195.19	156.44
r=2	r=3	109.97	144.18	141.81	168.18	144.50	162.04	99.83	132.22	138.49	127.27	125.29	119.03
r=3	r=4	71.60	97.67	88.89	109.26	84.78	97.12	48.14	81.78	84.42	70.81	75.79	85.44
r=4	r=5	39.85	57.60	45.91	57.30	43.17	50.16	26.73	47.19	47.55	36.96	40.45	55.5
r=5	r=6	15.80	18.13	16.32	18.21	15.21	18.95	10.10	18.92	19.58	16.77	14.43	28.81

Table B5: Cointegration Rank Statistics for countries with 5 Exogenous Variables

H0	H1	Argentina	Chile	Malaysia	Philip.	Singapore	Thailand	India	Critical Values
									95%
Maximum Eigenvalue Statistics									
r = 0	r = 1	53.45	81.77	67.00	94.23	68.61	109.54	83.57	57.13
r = 1	r = 2	50.47	58.77	41.37	53.20	61.07	81.82	56.66	50.64
r = 2	r = 3	34.26	37.14	30.27	46.22	42.51	58.52	39.44	43.94
r = 3	r = 4	25.56	29.55	19.66	24.75	28.99	32.84	23.75	36.84
r = 4	r = 5	10.51	13.82	10.36	14.33	9.71	19.81	14.29	28.81
Trace Statistics									
r=0	r>1	174.26	221.05	168.67	232.73	210.90	302.52	217.71	156.44
r=1	r=2	120.81	139.29	101.67	138.50	142.29	192.99	134.14	119.03
r=2	r=3	70.34	80.51	60.30	85.30	81.22	111.17	77.48	85.44
r=3	r=4	36.08	43.37	30.03	39.08	38.71	52.65	38.04	55.5
r=4	r=5	10.51	13.82	10.36	14.33	9.71	19.81	14.29	28.81

Table B6: Cointegration Rank Statistics for Countries with 4 Exogenous Variables

H0	H1	China	Brazil	Mexico	Peru	Indon.	Turkey	Critical Values
								95%
Maximum Eigenvalue Statistics								
r=0	r=1	99.10	74.30	58.01	70.70	56.27	77.60	50.64
r=1	r=2	30.72	33.93	48.10	42.22	49.41	38.73	43.94
r=2	r=3	23.57	30.01	30.31	39.15	42.58	28.47	36.84
r=3	r=4	18.57	12.26	22.89	15.63	24.07	17.88	28.81
Trace Statistics								
r=0	r>1	171.97	150.50	159.30	167.70	172.32	162.68	119.03
r=1	r=2	72.86	76.20	101.29	96.99	116.06	85.08	85.44
r=2	r=3	42.14	42.27	53.20	54.77	66.65	46.35	55.5
r=3	r=4	18.57	12.26	22.89	15.63	24.07	17.88	28.81

Table B7: Cointegration Rank Statistics for the Saudi Arabian Model

H0	H1	S. Arabia	Critical Values
			95%
Maximum Eigenvalue Statistics			
r=0	r=1	54.33	43.94
r=1	r=2	35.97	36.84
r=2	r=3	20.37	28.81
Trace Statistics			
r=0	r>1	110.67	85.44
r=1	r=2	56.34	55.5
r=2	r=3	20.37	28.81

Table B8: Cointegration Rank Statistics for the US model

H0	H1	US	Critical Values
			95%
Maximum Eigenvalue Statistics			
r=0	r=1	92.49	54.24
r=1	r=2	56.87	47.99
r=2	r=3	32.77	41.66
r=3	r=4	20.37	35.19
r=4	r=5	16.18	28.43
r=5	r=6	6.76	20.98
Trace Statistics			
r=0	r>1	225.45	158.01
r=1	r=2	132.96	122.96
r=2	r=3	76.08	91.81
r=3	r=4	43.31	64.54
r=4	r=5	22.94	41.03
r=5	r=6	6.76	20.98

Table B9: VAR Lag Order and Number of Cointegrating Relationships

Country	VAR Lag order	#coint
China	2	1
Euro area	2	2
Japan	2	5
Argentina	2	2
Brazil	2	1
Chile	2	2
Mexico	2	2
Peru	2	2
Australia	1	4
Canada	1	5
New Z.	2	3
Indon.	2	3
Korea	2	4
Malaysia	2	1
Philippines	2	2
Singapore	2	2
Thailand	1	3
India	2	2
S. Africa	2	2
S. Arabia	2	2
Turkey	2	1
Norway	2	3
Sweden	2	3
Switz.	1	3
UK	2	3
USA	2	2

Table B10: F Statistics for Testing the Weak Exogeneity of the Country-Specific Foreign Variables and Oil prices

Country/Region	Foreign Variables							e*-p*
		y*	Dp*	q*	r*	lr*	oil	
USA	F=(2 , 75)	0.16	1.22	-	-	-	-	1.90
China	F=(1 , 72)	0.21	1.70	3.86	0.09	1.14	0.32	-
Euro area	F=(2 , 67)	0.09	0.00	2.36	0.22	2.07	2.31	-
Japan	F=(5 , 64)	0.63	0.86	0.67	1.48	1.32	1.28	-
Argentina	F=(2 , 69)	1.09	0.12	0.02	0.17	1.57	2.05	-
Brazil	F=(1 , 72)	0.12	1.65	0.29	0.91	0.17	0.35	-
Chile	F=(2 , 69)	0.57	0.68	1.40	1.40	1.32	1.42	-
Mexico	F=(2 , 71)	1.31	0.98	1.10	0.16	0.33	0.33	-
Peru	F=(2 , 71)	0.06	1.17	0.10	1.71	1.70	0.88	-
Australia	F=(4 , 79)	0.84	0.74	0.28	0.23	0.59	0.63	-
Canada	F=(5 , 78)	0.63	0.47	1.18	1.83	0.29	0.72	-
New Zealand	F=(3 , 66)	0.51	1.02	1.33	0.56	0.80	0.54	-
Indonesia	F=(3 , 70)	1.55	2.14	0.38	0.65	1.02	0.19	-
Korea	F=(4 , 65)	1.47	0.25	0.46	1.91	1.61	2.26	-
Malaysia	F=(1 , 70)	1.19	2.30	0.10	0.02	0.62	1.54	-
Philippines	F=(2 , 69)	0.95	2.19	0.53	0.56	0.55	3.51*	-
Singapore	F=(2 , 69)	1.41	0.69	0.21	0.74	0.28	0.64	-
Thailand	F=(3 , 81)	1.70	0.63	0.74	1.60	0.15	1.87	-
India	F=(2 , 69)	0.73	0.59	2.46	0.60	1.07	2.31	-
S. Africa	F=(2 , 67)	0.31	0.22	0.07	1.24	0.14	0.15	-
S. Arabia	F=(2 , 73)	0.72	0.71	0.68	0.13	0.43	0.01	-
Turkey	F=(1 , 72)	3.11	0.06	0.40	0.02	0.17	0.77	-
Norway	F=(3 , 66)	0.57	2.81*	0.84	0.59	0.54	0.82	-
Sweden	F=(3 , 66)	2.47	1.49	0.08	0.40	0.30	0.51	-
Switzerland	F=(3 , 80)	1.56	0.71	0.67	0.95	0.41	1.29	-
UK	F=(3 , 66)	1.88	0.24	0.39	1.11	0.83	1.04	-

Table B11: Contemporaneous Effects of Foreign Variables on Their Domestic Counterparts in Country-Specific Models

Country/Region	γ	Dp	q	r	lr
China	0.086 (0.158)	1.472* (0.707)	-	0.136* (0.069)	-
Euro area	0.498* (0.105)	0.117 (0.081)	1.159 (0.082)	0.094* (0.023)	0.625* (0.079)
Japan	0.324 (0.190)	0.526* (0.115)	0.581* (0.141)	-0.037 (0.049)	0.394* (0.101)
Argentina	0.491 (0.320)	-2.220 (0.923)	1.247* (0.532)	2.687* (0.850)	-
Brazil	0.568 (0.414)	3.317* (0.966)	-	-2.915* (1.322)	-
Chile	0.564 (0.362)	-0.027 (0.136)	0.398* (0.181)	-0.022 (0.083)	-
Mexico	0.695 (0.525)	0.193 (0.759)	-	-0.294 (0.812)	-
Peru	-0.466 (0.850)	1.628 (2.373)	-	-1.367 (0.985)	-
Australia	0.536* (0.174)	0.273 (0.151)	0.997* (0.100)	0.444* (0.148)	0.856* (0.162)
Canada	0.409* (0.115)	0.696* (0.120)	1.067* (0.074)	0.556* (0.134)	0.989* (0.056)
New Z.	0.694* (0.313)	0.328 (0.232)	0.979* (0.205)	0.423 (0.300)	0.234 (0.201)
Indon.	0.577 (0.514)	-0.315 (0.631)	-	1.207 (0.644)	-
Korea	1.012* (0.455)	0.301 (0.215)	1.004* (0.200)	-0.200 (0.136)	-0.271 (0.321)
Malaysia	1.510* (0.338)	0.057 (0.178)	1.598 (0.388)	0.077 (0.154)	-
Philippines	0.237 (0.408)	-1.085* (0.504)	1.788* (0.351)	0.889 (0.455)	-
Singapore	0.929* (0.354)	0.429* (0.155)	0.123 (0.177)	0.498* (0.149)	-
Thailand	-0.080 (0.283)	1.097* (0.182)	0.992* (0.164)	0.844* (0.335)	-
India	0.903* (0.387)	0.132 (0.538)	0.810* (0.211)	-0.192 (0.323)	-
S. Africa	-0.152 (0.223)	0.180 (0.248)	1.021* (0.145)	0.135 (0.099)	0.252 (0.268)
S. Arabia	0.239 (0.455)	-0.021 (0.270)	-	-	-
Turkey	0.943 (0.653)	7.784* (1.527)	-	1.918 (0.997)	-
Norway	1.199* (0.383)	1.008* (0.196)	0.986* (0.134)	0.195 (0.107)	0.555* (0.148)
Sweden	0.295 (0.313)	1.301* (0.239)	1.263* (0.118)	1.201* (0.295)	0.878* (0.142)
Switz.	0.474* (0.117)	0.507* (0.135)	0.700* (0.131)	0.142* (0.065)	0.411* (0.073)
UK	0.444* (0.143)	0.473 (0.255)	0.871* (0.071)	0.239 (0.162)	0.745* (0.141)
USA	0.336* (0.101)	0.053 (0.063)	-	-	-

Note: * denotes statistical significance at the 5% level or less. Standard errors are in parentheses.

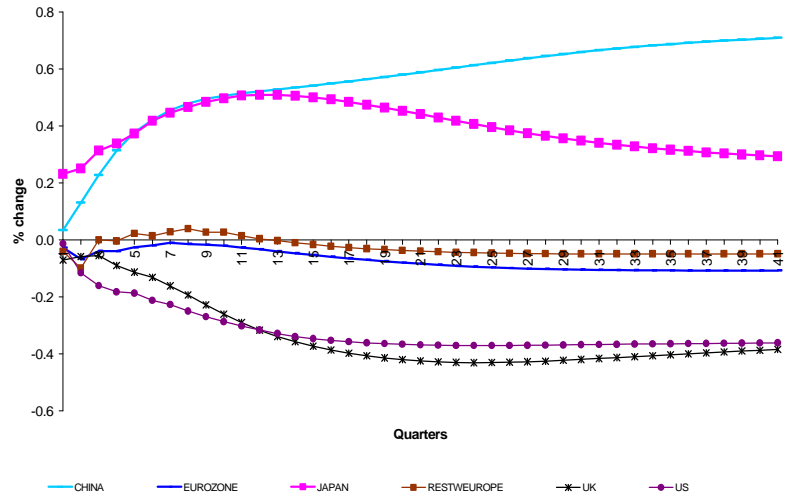


Figure A1: Impulse Response of a Positive (+1 s.e.) Shock to Oil Prices on Real Output Across Regions

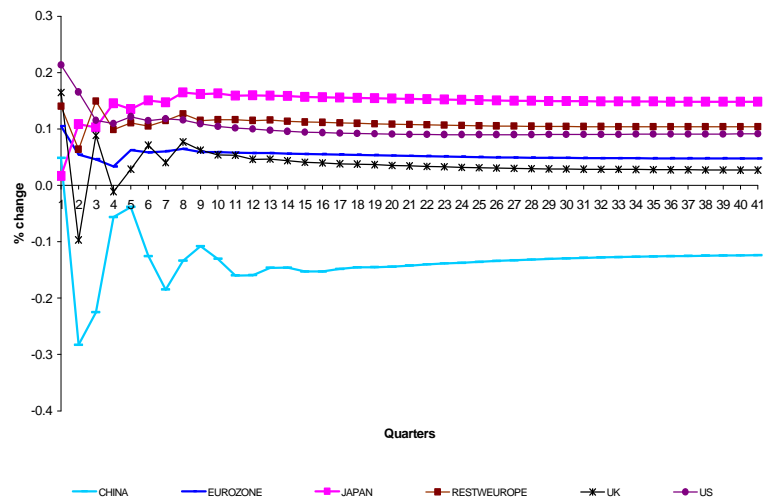


Figure A2: Impulse Response of a Positive (+1 s.e.) Shock to Oil Prices on Inflation Across Regions

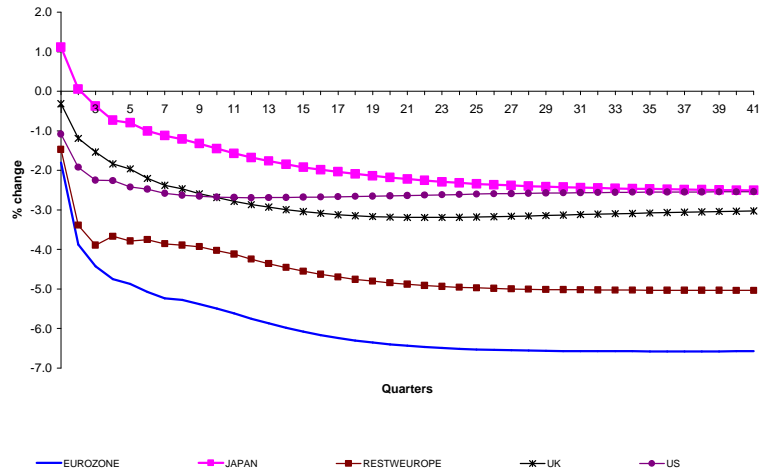


Figure A3: Impulse Response of a Positive (+1 s.e.) Shock to Oil Prices on Real Equity Prices Across Regions

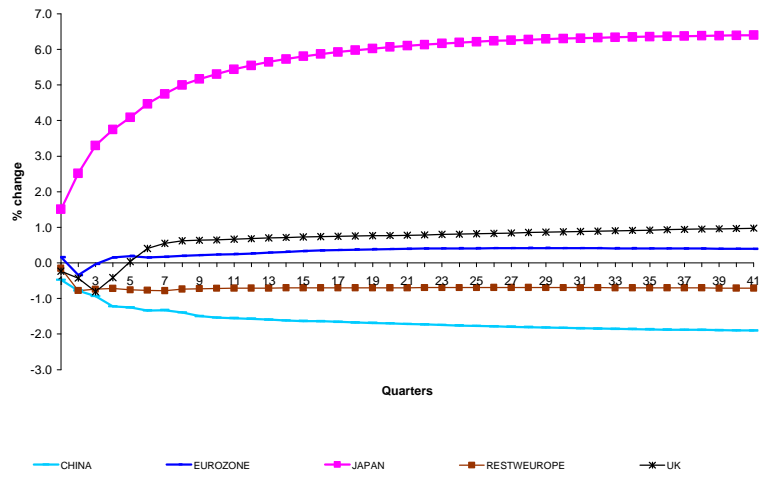


Figure A4: Impulse Response of a Positive (+1 s.e.) Shock to Oil Prices on Real Exchange Rates Across Regions

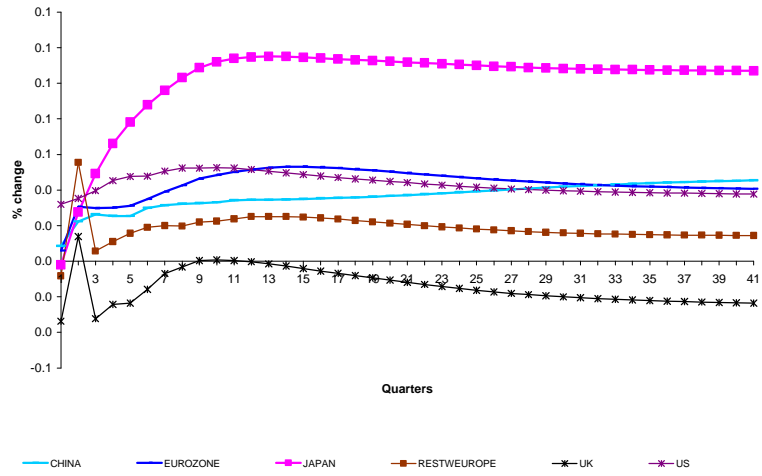


Figure A5: Impulse Response of a Positive (+1 s.e.) Shock to Oil Prices on Short Term Interest Rates Across Regions

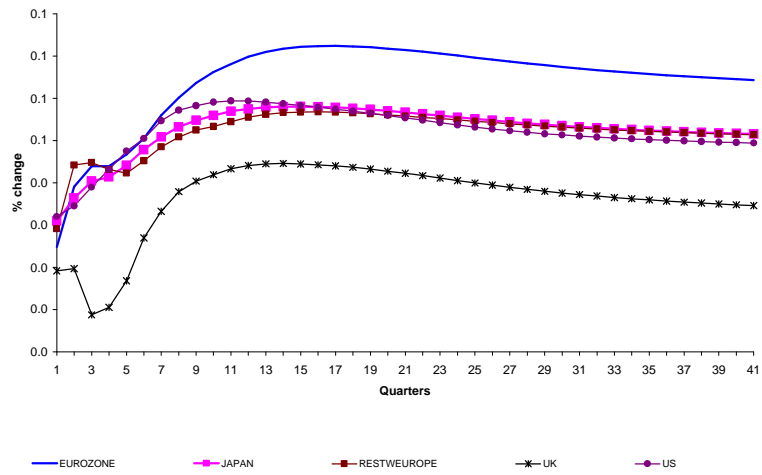


Figure A6: Impulse Response of a Positive (+1 s.e.) Shock to Oil Prices on Interest Rate Spreads Across Regions

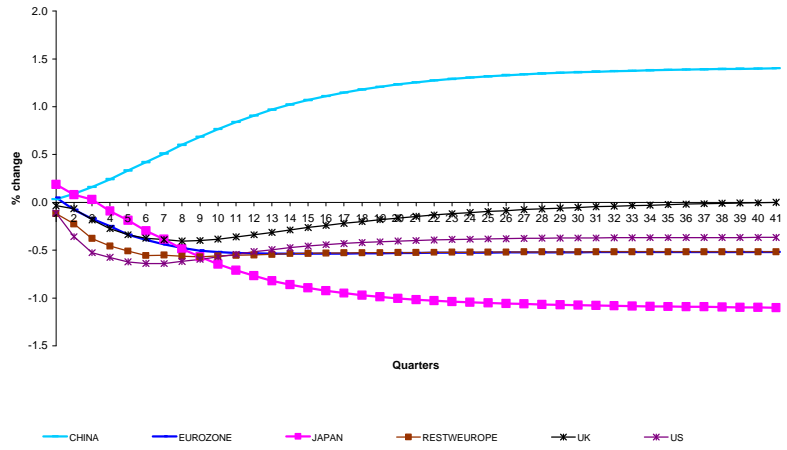


Figure A7: Impulse Response of a Negative (-1 s.e.) Shock to US Real Equity Prices on Real Output Across Regions

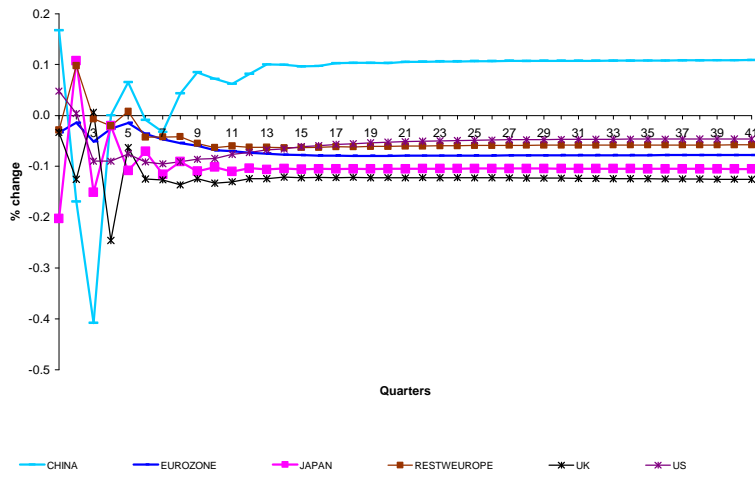


Figure A8: Impulse Response of a Negative (-1 s.e.) Shock to US Real Equity Prices on Inflation Across Regions

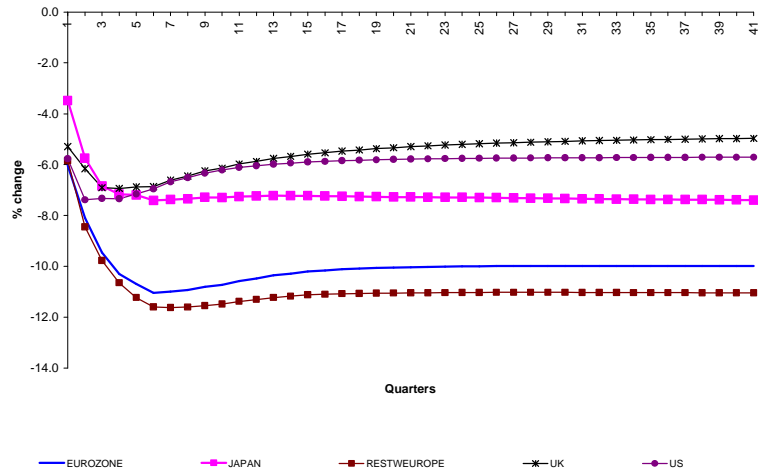


Figure A9: Impulse Response of a Negative (-1 s.e.) Shock to US Real Equity Prices on Real Equity Prices Across Regions

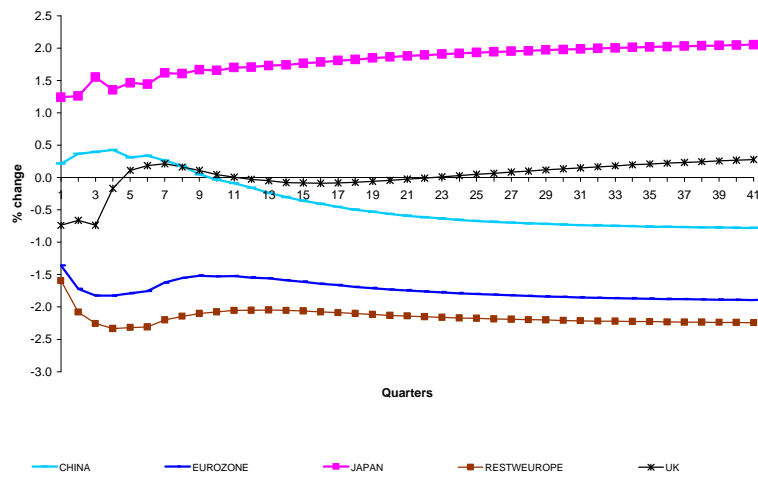


Figure A10: Impulse Response of a Negative (-1 s.e.) Shock to US Real Equity Prices on Real Exchange Rates Across Regions

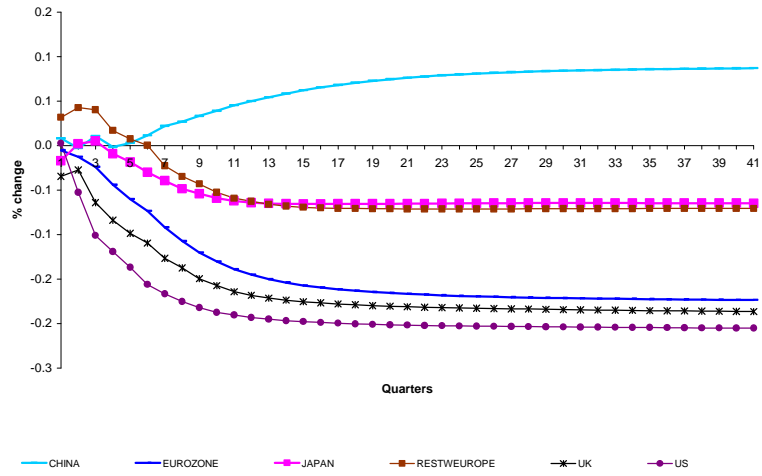


Figure A11: Impulse Response of a Negative (-1 s.e.) Shock to US Real Equity Prices on Short Term Interest Rates Across Regions

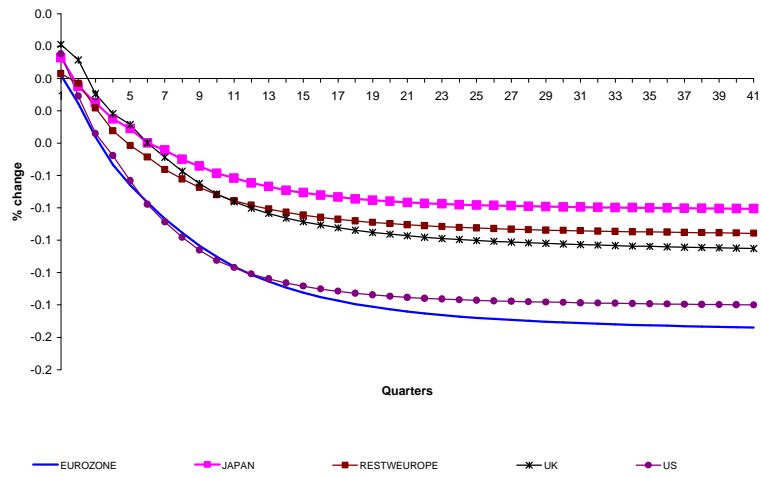


Figure A12: Impulse Response of a Negative (-1 s.e.) Shock to US Real Equity Prices on Interest Rate Spreads Across Regions

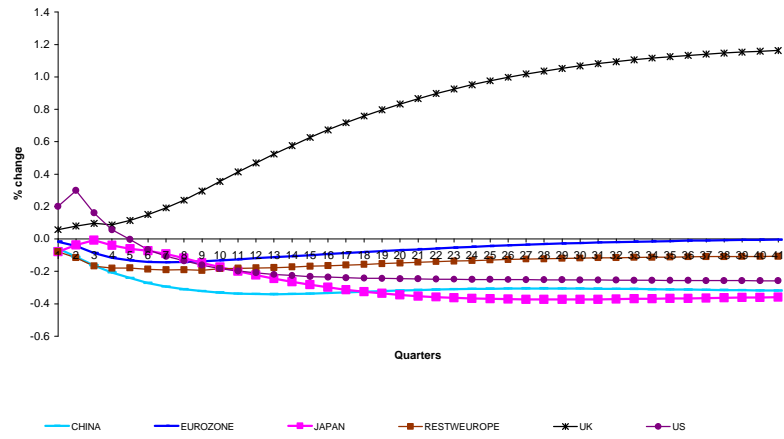


Figure A13: Impulse Response of a Positive (+1 s.e.) Shock to US Short Term Interest Rate on Real Output Across Regions

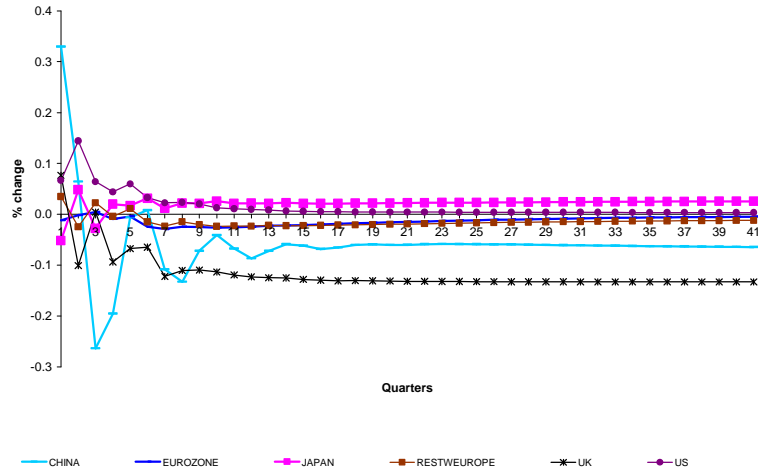


Figure A14: Impulse Response of a Positive (+1 s.e.) Shock to US Short Term Interest Rate on Inflation Across Regions

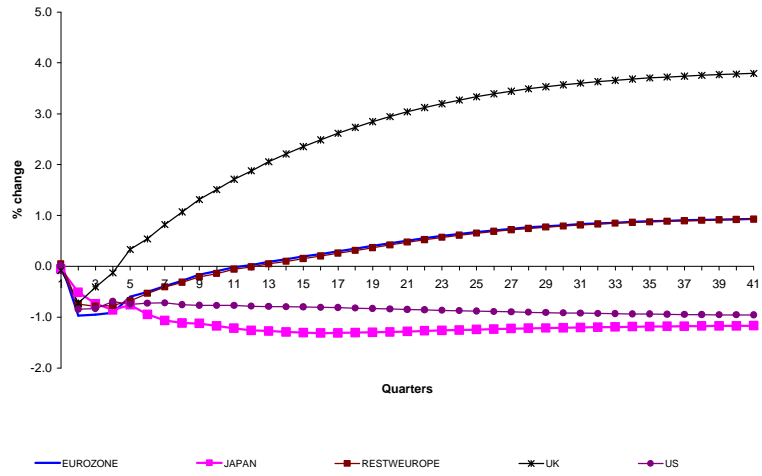


Figure A15: Impulse Response of a Positive (+1 s.e.) Shock to US Short Term Interest Rate on Real Equity Prices Across Regions

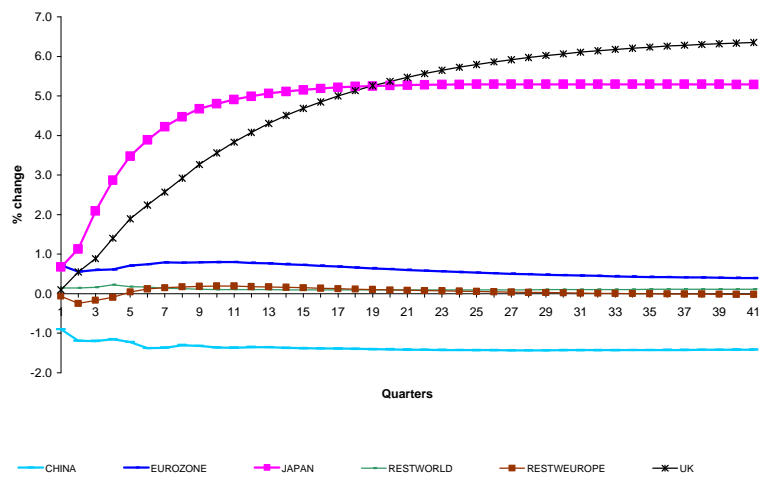


Figure A16: Impulse Response of a Positive (+1 s.e.) Shock to US Short Term Interest Rate on Real Exchange Rates Across Regions

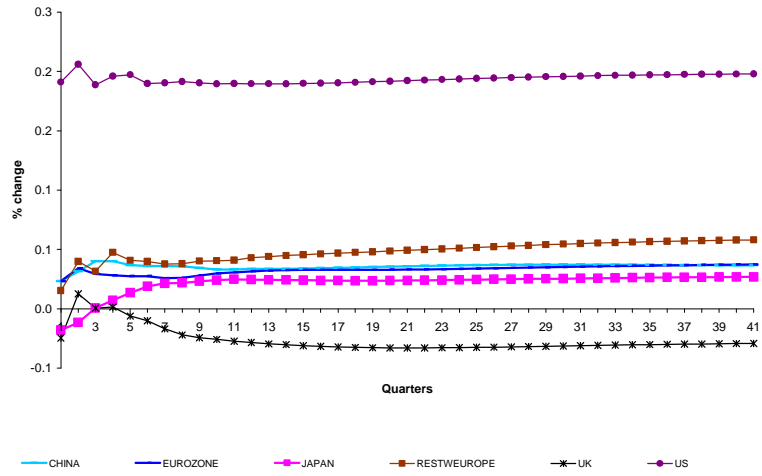


Figure A17: Impulse Response of a Positive (+1 s.e.) Shock to US Short Term Interest Rate on Short Term Interest Rates Across Regions

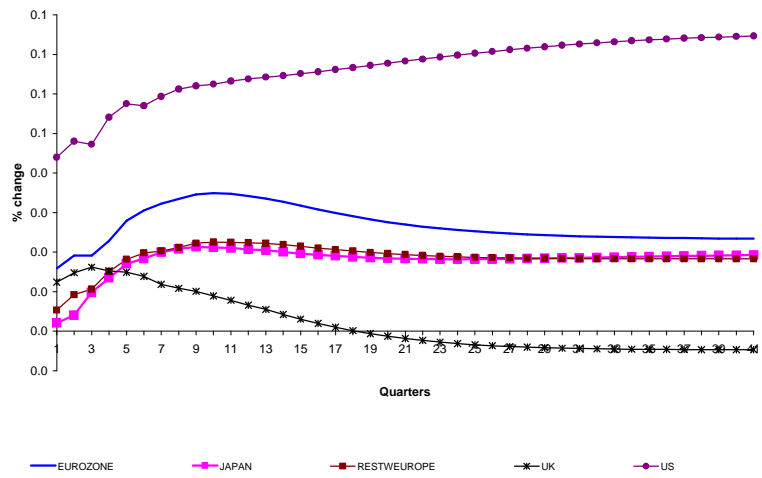


Figure A18: Impulse Response of a Positive (+1 s.e.) Shock to US Short Term Interest Rate on Interest Rate Spreads Across Regions

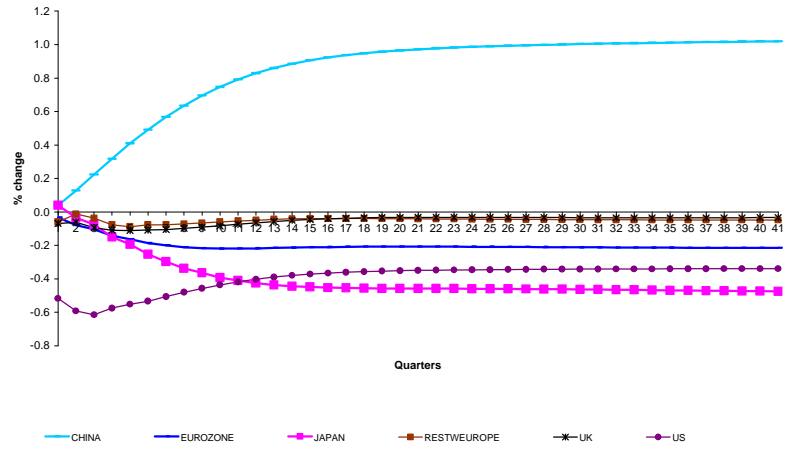


Figure A19: Impulse Response of a Negative (-1 s.e.) Shock to US Real Output on Real Output Across Regions

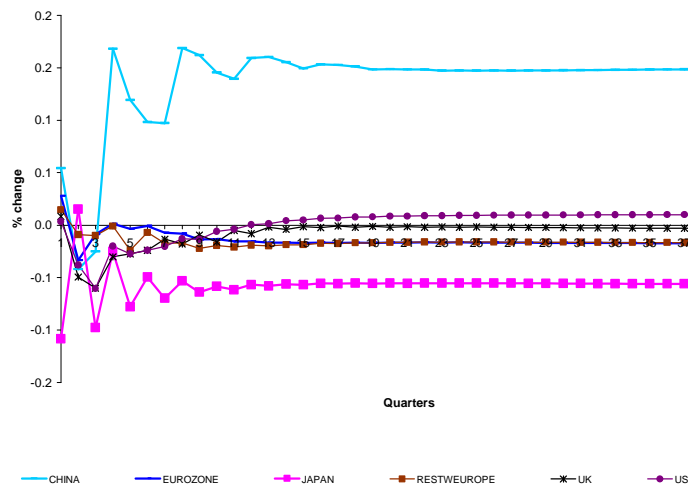


Figure A20: Impulse Response of a Negative (-1 s.e.) Shock to US Real Output on Inflation Across Regions

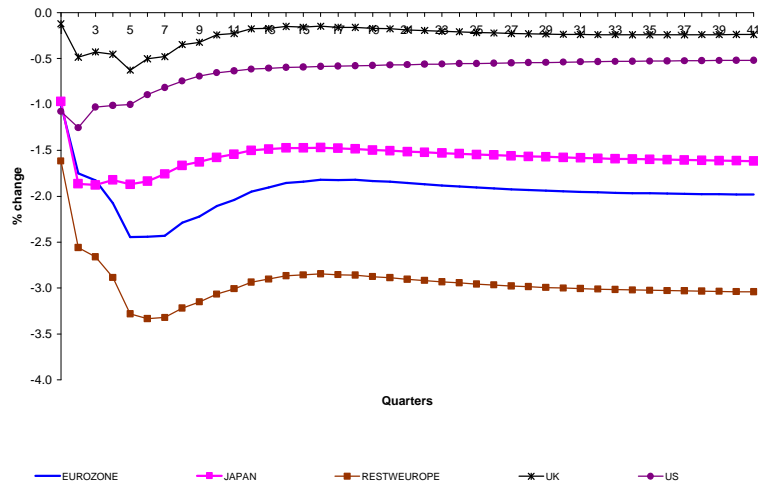


Figure A21: Impulse Response of a Negative (-1 s.e.) Shock to US Real Output on Real Equity Prices Across Regions

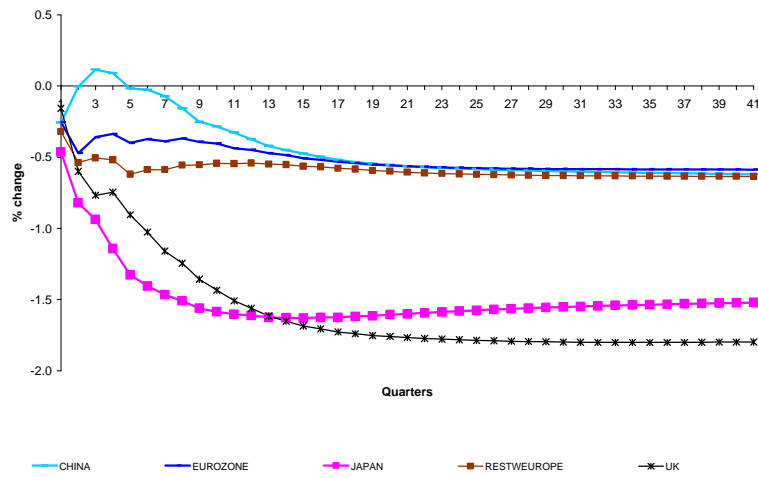


Figure A22: Impulse Response of a Negative (-1 s.e.) Shock to US Real Output on Real Exchange Rates Across Regions

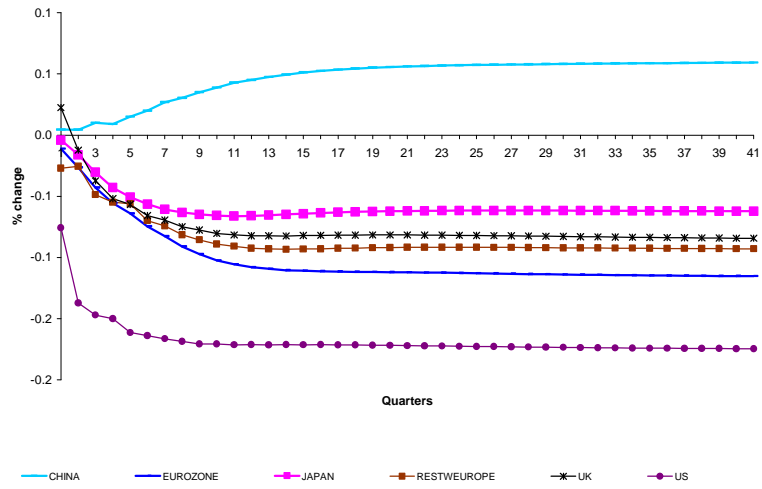


Figure A23: Impulse Response of a Negative (-1 s.e.) Shock to US Real Output on Short Term Interest Rates Across Regions

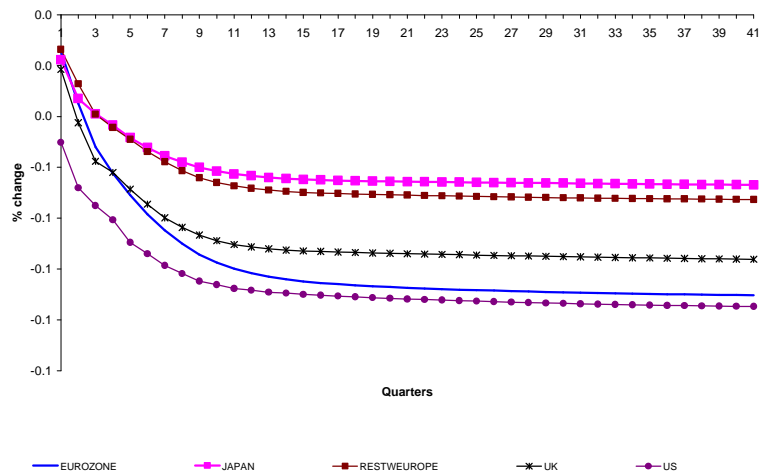


Figure A24: Impulse Response of a Negative (-1 s.e.) Shock to US Real Output on Interest Rate Spreads Across Regions