THE UNIVERSITY OF MELBOURNE

FACULTY OF BUSINESS & ECONOMICS

Melbourne Institute Working Paper Series

Working Paper No. 18/12

International Linkages of the Korean Economy: The Global Vector Error-Correcting Macroeconometric Modelling Approach

Matthew Greenwood-Nimmo, Viet Hoang Nguyen and Yongcheol Shin

MELBOURNE INSTITUTE®
of Applied Economic and Social Research

International Linkages of the Korean Economy: The Global Vector Error-Correcting Macroeconometric Modelling Approach*

Matthew Greenwood-Nimmo†, Viet Hoang Nguyen‡ and Yongcheol Shin§

† Leeds University Business School, University of Leeds

‡ Melbourne Institute of Applied Economic and Social Research, The University of Melbourne

§ Department of Economics and Related Studies, University of York

Melbourne Institute Working Paper No. 18/12

ISSN 1328-4991 (Print)

ISSN 1447-5863 (Online)

ISBN 978-0-7340-4278-1

August 2012

* Corresponding Author: Y. Shin, A/EC/119 Department of Economics and Related Studies, University of York, Heslington, York, UK, YO10 5DD. Email: yongcheol.shin@york.ac.uk. We are grateful for helpful comments by Kanguk Choi, Youngil Choi, Filippo di Mauro, Ana-Maria Fuertes, Heedon Kang, Yangsoo Park, Hashem Pesaran, Vanessa Smith and Mike Wickens. The constructive discussion of seminar participants at the Universities of Cape Town, Leeds and York, and of conference delegates at the 38th Annual Conference of the Eastern Economic Association (Boston, February 2012) and the Birmingham Macroeconomics and Econometrics Conference (Birmingham, May 2012) is also gratefully acknowledged. The usual disclaimer applies.

Melbourne Institute of Applied Economic and Social Research

The University of Melbourne

Victoria 3010 Australia

***Telephone* (03) 8344 2100**

***Fax* (03) 8344 2111**

***Email* melb-inst@unimelb.edu.au**

***WWW Address* http://www.melbourneinstitute.com**

Abstract

This paper analyses the international linkages of the Korean economy using the GVAR model developed by Greenwood-Nimmo, Nguyen and Shin (2012a, *J. Appl. Econometrics*). By employing a combination of generalised impulse response analysis and forecast error variance decompositions, we uncover a number of interesting phenomena. Among our most important results are the findings that the real economy and the financial markets are highly sensitive to the oil price even though it has little effect on inflation and that the interest rate is set largely without recourse to overseas conditions except to the extent that they are captured by the exchange rate. We find that the dominant sources of overseas influence on the Korean economy are the US, the Eurozone, Japan and China. Korea's complex and open linkages with these countries will inevitably pose challenges for domestic economic management and stabilisation policy faced by the Korean monetary and fiscal authorities**.**

JEL classification: C32, C53, E17

Keywords: Global VAR, impulse response analysis, forecast error variance decomposition, Korean macroeconomic international linkages

1 Introduction

Traditional approaches to macroeconometric modelling are typically focused on the national level, albeit sometimes with the inclusion of one or more satellite models representing important trading partners or the rest of the world economies. A good example of such a country-specific model in the case of Korea is Shin (2009). The principle limitation to the development of larger scale multi-country and global models has been the curse of dimensionality. Indeed, the construction of a pth order cointegrating VAR model in m core variables for each of $N+1$ separate economies would necessitate the estimation of $mp(N+1)$ parameters. The dimensionality of such a model clearly increases proportionately with m, N and p, rendering it an infeasible approach for the analysis of anything but relatively simple and naïve systems given the range and frequency of most existing macroeconomic datasets.

The global vector autoregressive (GVAR) framework developed in a sequence of papers by Pesaran, Schuermann and Weiner (2004, PSW), Dees, di Mauro, Pesaran and Smith (2007, DdPS) and Dees, Holly, Pesaran and Smith (2007, DHPS) offers a new approach to large scale macroeconometric modelling that circumvents this issue. The main innovation of GVAR is the exploitation of an underlying linking scheme by which $N+1$ country-specific VARX models are combined into a coherent global system. This is achieved by the inclusion of weakly exogenous foreign variables within each country-specific model. These foreign variables are defined as weighted averages of the variables in the remaining N countries in the global system (*i.e.* the foreign variables for country i are defined as appropriately weighted averages of the corresponding variables for all countries $j \neq i$). It is the use of mutually consistent bilateral weights that provides the desired linkages required to construct the global system.

By virtue of their ability to explicitly model national, regional and global linkages, GVAR models represent a powerful tool for the analysis of global phenomena, including business cycle linkages (*e.g.* DdPS; DHPS), financial contagion (*e.g.* PSW; Chen et al., 2009; Sgherri and Galesi, 2009) and global imbalances (*e.g.* Bussière et al., 2009; Greenwood-Nimmo, Nguyen and Shin, 2012a, GNS; Greenwood-Nimmo, Nguyen and Shin, 2012b). This paper employs the GVAR model developed by GNS to investigate the international linkages of the South Korean economy. The GNS model is estimated for the same group of 33 countries (26 regions) considered by DdPS and DHPS over the extended sample period 1980Q2-2007Q2. However, unlike these papers, the GNS model includes real exports and imports in order to facilitate the analysis of global trade imbalances. Furthermore, the country-specific models embedded within the GNS framework are based upon the CVARX model of Shin (2009) in the sense that they allow for one-time permanent intercept shifts in selected countries that have suffered acute and disruptive events during the sample period. In particular, the GNS model accounts for the 1997 Asian banking crisis, the introduction of the Euro, the Japanese real estate collapse, the Black Wednesday event in the UK and the various South American hyperinflationary episodes.

The original application of the GNS model was to the probabilistic forecasting of scenarios relating to inflation, output growth and the balance of trade in a focus group of four countries (the USA, the Eurozone, Japan and China). Subsequently, the model has been applied to the counterfactual analysis of policy-relevant scenarios in the same group of focus countries by exploiting linear combinations of generalised impulse response functions, or GIRFs (Greenwood-Nimmo, Nguyen and Shin, 2012b). In this paper, our focus is upon more extended impulse response analysis and forecast error variance decomposition (FEVD) as tools with which to assess the bidirectional connections or linkages between Korea and the global economy.

Our results provide a number of interesting insights. Firstly, impulse response analysis reveals that the real side of the Korean macroeconomy is highly sensitive to the price of crude oil while the nominal side exhibits a relatively muted response, presumably reflecting the interventionist energy policies enacted in the earlier years of our sample. Next, one important, if unsurprising, finding is that both the financial and real sides of the Korean economy respond rapidly and strongly to the US stock market, reflecting Korea's integration into the global financial community. Importantly, we also find that the prospects of the Korean economy are not only intimately linked with those of the US but also of China. Such strong external influences will significantly complicate the task of domestic macroeconomic management faced by the Korean monetary and fiscal authorities.

In a step beyond the widespread practice in the GVAR literature, we analyse the h step ahead FEVDs of a given Korean domestic variable in terms of its own contribution to the variance share, the contribution of the remaining domestic variables, the contribution of the oil price and the contribution of the remaining foreign variables in the global system. In this way, we find that with the exception of the interest rate, the remaining Korean variables respond strongly to conditions overseas. At an over-arching level, our analysis reveals that the prospects of the Korean economy are closely linked to the core macroeconomic performance of the US economy, the performance of the American, European and Japanese stock markets and the performance of the Chinese economy, especially in terms of inflation. To reiterate a point from above, these close international linkages will inevitably complicate the task of economic management and stabilisation.

This paper proceeds in 6 sections. Section 2 introduces the GNS GVAR model and discusses the framework for dynamic analysis, while Section 3 provides some preliminary analysis of the dataset used, draws out some stylised facts and summarises a range of pre-testing exercises conducted in GNS. Section 4 evaluates the impact of a range of shocks on the Korean economy by means of impulse response analysis, while Section 5 identifies key global variables relevant for Korea using forecast error variance decompositions. Section 6 concludes. Detailed notes on the dataset are contained in an Appendix.

2 The GNS GVAR Model

The need for sophisticated multi-country and global models has become increasingly apparent with the deepening and widening of both regional and global linkages associated with the continuing process of globalisation. However, the development and estimation of global macroeconometric models has generally proven infeasible due to the curse of dimensionality. Much of the existing research into two-country and multi-country modelling has therefore employed calibrated DSGE models. Notable examples include de Walque et al. (2005), Cristadoro et al. (2006) and the IMF's Global Economy Model (GEM) and Global Fiscal Model (GFM), which are neatly summarised by Bayoumi (2004) and Botman et al. (2007). Nevertheless, large scale multi-country DSGE models remain relative rare due to the complexity of the modelling that is required to deliver the rich microfoundations that are considered the principle advantage of DSGE models relative to more data-driven approaches such as VAR.

The GVAR Error-Correcting framework represents an alternative and complementary approach to the so-called new open economy macroeconomics (NOEM) paradigm. The contrast between the ease of estimation and empirical strength of VAR and the benefits of the theoretical microfoundations of DSGE models has been well documented (Pagan, 2003). The construction of a DSGE model where the number of countries exceeds two or three is highly computationally demanding and it is here that GVAR enjoys a distinct advantage. The principle of parsimony suggests that the relatively more simple but flexible GVAR specification should be preferred to the DSGE model in terms of out-of-sample forecasting if it can provide a similar degree of accuracy.[1] Moreover, one may prefer a comparatively unrestricted GVAR model to a DSGE model with its inherent reliance on deep parameters and behavioural assumptions, particularly if one follows the logic of Sims (1980) in terms of letting the data 'speak for itself'.[2]

The remainder of this section provides a detailed derivation of the GNS GVAR model. As will become clear, the principle innovation of GVAR relative to more traditional approaches to large-scale macroeconometric modelling is the construction of country-specific CVARX* models that include weakly exogenous foreign variables. These foreign variables are computed as weighted averages of the corresponding variables for each of the remaining countries in the global system (*i.e.* in a three country system, country 1's foreign GDP series would be a weighted average of the GDP of countries 2 and 3). This approach introduces fundamental linkages between the country-specific CVARX* models which may be exploited by means of carefully constructed link matrices, thereby allowing one to combine the country-specific models into a global system. In this way, GVAR models may be constructed for large global systems, the dimensionality of which would preclude their estimation using traditional techniques.

2.1 National Modelling

Shin (2009) develops a small quarterly macroeconometric model for Korea following the long-run structural modelling approach of GLPS. The model is estimated over the period 1982q3–2006q2 in six endogenous domestic variables and three weakly exogenous foreign variables. Among the domestic variables are the bilateral nominal KRW/USD exchange rate, the nominal 90 day money market rate, the rate of consumer price inflation, real per capita GDP, producer prices relative to the OECD countries and the ratio of real per capita M1 to real GDP. Similarly, the foreign variables include the price of crude oil, the US nominal 90 day Treasury Bill rate and real per capita GDP for the OECD economies. Importantly, Shin extends the long-run structural modelling approach associated with Pesaran and Shin (2002) by incorporating a common one-time permanent intercept shift at 1997q4 in the CVARX* model. Shin argues that the inclusion of break dummies is important in this case as it accounts for the repercussions of the 1997 East Asian banking crisis on the Korean macroeconomy in the short-run as well as in relation to its governing long-run economic relations.

[1] It must be noted, however, that recent advances in Bayesian DSGE modelling have significantly narrowed the gap in forecasting performance (*c.f.* Smets and Wouters, 2007, and Adolfson et al., 2007).

[2] A number of interesting intermediate cases obtain between the extremes of unrestricted VAR and DSGE, including over-identified cointegrating VAR and DSGE-VAR (*c.f.* Del Negro and Schorfheide, 2004).

The GVAR model developed by GNS continues in this vein by incorporating country-specific structural breaks within the global framework. The same 26 countries/regions studied by DdPS are included, as summarised in Table 1 which reproduces part of Table 1 from GNS. It also records the timing and probable cause of the structural breaks included in the country-specific and global models. GNS argue that explicit inclusion of structural breaks will improve the accuracy of their estimation and forecasting results, especially for the East Asian economies (including Korea) and for the South American countries that recorded hyperinflationary episodes in the 1980s. Further breaks are included to account for the introduction of the Euro, the Japanese real-estate collapse and the Black Wednesday event in the UK.

[Insert Table 1 about here]

Two key differences between Shin's model and the country-specific model for Korea embedded within the GNS GVAR model are: (i) the selection of endogenous and exogenous variables in each case; in particular, the scope of the GNS model is broader, including the domestic and foreign equity prices and the trade variables (real exports and imports), though the monetary aggregate variables cannot be accommodated in the global model mainly due to difficulties in collecting those homogenous aggregates across countries in a consistent way; and (ii) the more general construction of the weakly exogenous foreign variables as trade-weighted averages in GNS but simply as the relevant US or OECD variables in Shin. We would therefore expect each model to have different strengths.

Adopting the notation used in GNS, the model comprises $N+1$ economies indexed by $i = 0, 1, .., N$. For each country-specific model, the set of domestic variables are denoted by an $m_i \times 1$ vector, $\boldsymbol{x}_{it}$ and the associated country-specific foreign variables by an $m_i^* \times 1$ vector $\boldsymbol{x}_{it}^*$ defined as $\boldsymbol{x}_{it}^* = \sum_{j=0}^{N} w_{ij} \boldsymbol{x}_{jt}$, where $w_{ij} \geq 0$ are the weights attached to the foreign variables with $\sum_{j=0}^{N} w_{ij} = 1$, and $w_{ii} = 0$ for all i. PSW show that the definition of the weakly exogenous foreign variables for country i as weighted averages of variables for countries, $j \neq i$, results in a simultaneous system of equations that may be solved to form a global system. The exploitation of these linkages represents the key innovation of the Global VAR framework.

Following Shin, GNS write the second order country-specific VARX* $(2, 2)$ model as

$$\begin{aligned} \boldsymbol{x}_{it} &= \boldsymbol{h}_{i0} + \boldsymbol{h}_{i1} t + \boldsymbol{\delta}_{i0} d_{it} + \boldsymbol{\delta}_{i1} d_{i,t-1} + \boldsymbol{\delta}_{i2} d_{i,t-2} + \boldsymbol{\Phi}_{i1} \boldsymbol{x}_{i,t-1} \\ &+ \boldsymbol{\Phi}_{i2} \boldsymbol{x}_{i,t-2} + \boldsymbol{\Psi}_{i0} \boldsymbol{x}_{it}^* + \boldsymbol{\Psi}_{i1} \boldsymbol{x}_{i,t-1}^* + \boldsymbol{\Psi}_{i2} \boldsymbol{x}_{i,t-2}^* + \boldsymbol{u}_{it}, \end{aligned} \tag{1}$$

where d_{it} is the country-specific intercept shift variable and $\boldsymbol{u}_{it} \sim iid\left(0, \boldsymbol{\Sigma}_{ii}\right)$, where $\boldsymbol{\Sigma}_{ii}$ is an $m_i \times m_i$ positive definite variance-covariance matrix. The coefficient vectors $\boldsymbol{h}_{ij}$, $j = 0, 1$ and $\boldsymbol{\delta}_{ij}$, $j = 0, 1, 2$, are of dimension $m_i \times 1$, while $\boldsymbol{\Phi}_{ij}$, $j = 1, 2$, and $\boldsymbol{\Psi}_{ij}$, $j = 0, 1, 2$, are $m_i \times m_i$ and $m_i \times m_i^*$ matrices, respectively.

The country-specific CVARX* models are estimated allowing for unit roots and cointegration using the Johansen eigenvalue routine under the assumption that the country-specific foreign variables are weakly exogenous. Hence, the VECM form of (1) may be written as

$$\begin{aligned} \Delta \boldsymbol{x}_{it} &= \boldsymbol{c}_{i0} + \boldsymbol{c}_{i0}^* \Delta d_{it} + \boldsymbol{c}_{i1}^* \Delta d_{i,t-1} + \boldsymbol{\Lambda}_i \Delta \boldsymbol{x}_{it}^* + \boldsymbol{\Gamma}_i \Delta \boldsymbol{z}_{i,t-1} \\ &+ \boldsymbol{\alpha}_i \boldsymbol{\beta}_i' \left(\boldsymbol{z}_{i,t-1} - \boldsymbol{\mu}_i d_{i,t-1} - \boldsymbol{\gamma}_i (t-1)\right) + \boldsymbol{u}_{it}, \end{aligned} \tag{2}$$

where $\boldsymbol{z}_{it} = \left(\boldsymbol{x}_{it}', \boldsymbol{x}_{it}^{*\prime}\right)'$, $\boldsymbol{\alpha}_i$ is the $m_i \times r_i$ country-specific matrix of adjustment coefficients of rank r_i and $\boldsymbol{\beta}_i$ is the $(m_i + m_i^*) \times r_i$ long-run matrix of rank r_i. Noting that $\boldsymbol{\beta}_i' \left(\boldsymbol{z}_{it} - \boldsymbol{\mu} d_{it} - \boldsymbol{\gamma}_i t\right)$ can be decomposed into $\boldsymbol{\beta}_{ix}' \boldsymbol{x}_{it} + \boldsymbol{\beta}_{ix^*}' \boldsymbol{x}_{it}^* - \left(\boldsymbol{\beta}_i' \boldsymbol{\mu}_i\right) d_t - \left(\boldsymbol{\beta}_i' \boldsymbol{\gamma}_i\right) t$, it is straightforward to test the co-trending restrictions, $\boldsymbol{\beta}_i' \boldsymbol{\gamma}_i = 0$, and the co-breaking restrictions, $\boldsymbol{\beta}_i' \boldsymbol{\mu}_i = 0$.

It follows that (1) can be written more compactly as

$$\boldsymbol{A}_{i0} \boldsymbol{z}_{it} = \boldsymbol{h}_{i0}^* + \boldsymbol{h}_{i1} t + \boldsymbol{A}_{i1} \boldsymbol{z}_{i,t-1} + \boldsymbol{A}_{i2} \boldsymbol{z}_{i,t-2} + \boldsymbol{u}_{it}, \tag{3}$$

where

$$\underset{m_i \times \left(m_i + m_i^*\right)}{\boldsymbol{A}_{i0}} = \left(\boldsymbol{I}_{m_i}, -\boldsymbol{\Psi}_{i0}\right); \quad \underset{m_i \times \left(m_i + m_i^*\right)}{\boldsymbol{A}_{i1}} = \left(\boldsymbol{\Phi}_{i1}, \boldsymbol{\Psi}_{i1}\right); \quad \underset{m_i \times \left(m_i + m_i^*\right)}{\boldsymbol{A}_{i2}} = \left(\boldsymbol{\Phi}_{i2}, \boldsymbol{\Psi}_{i1}\right);$$

$$\boldsymbol{h}_{i0}^* = \boldsymbol{h}_{i0} + \boldsymbol{\delta}_{i0} d_{it} + \boldsymbol{\delta}_{i1} d_{i,t-1} + \boldsymbol{\delta}_{i2} d_{i,t-2},$$

and where the parameters of (3) are related to those of (2) as follows

$$\boldsymbol{A}_{i0} = \left(\boldsymbol{I}_{m_i}, -\boldsymbol{\Lambda}_{i0}\right); \ \boldsymbol{A}_{i1} = \boldsymbol{A}_{i0} + \boldsymbol{\Pi}_i + \boldsymbol{\Gamma}_i; \ \boldsymbol{A}_{i2} = -\boldsymbol{\Gamma}_i; \tag{4}$$

$$\boldsymbol{h}_{i0}^* = \boldsymbol{c}_{i0} + \boldsymbol{c}_{i0}^* \Delta d_{it} + \boldsymbol{c}_{i1}^* \Delta d_{i,t-1} + \left(-\boldsymbol{\Pi}_i \boldsymbol{\mu}_i\right) d_{i,t-1}; \ \boldsymbol{h}_{i1} = -\boldsymbol{\Pi}_i \boldsymbol{\gamma}_i. \tag{5}$$

where $\boldsymbol{\Pi}_i = \boldsymbol{\alpha}_i \boldsymbol{\beta}_i'$. The extension to higher order VARX* systems is trivial.

The selection of variables used by GNS is based on that of DdPS, but with the exclusion of long-term interest rates and the inclusion of real exports and imports. Therefore, the core variables are the log of real per capita output (y_{it}), the log of the general price level (p_i), the rate of price inflation (Δp_{it}), the log of exports (x_{it}), the log of imports (m_{it}), the short term interest rate (r_{it}), the log of the nominal exchange rate in terms of the US Dollar (e_{it}), the log of real equity prices (q_{it}), and the log of the nominal spot oil price (p_t^o). The corresponding country-specific foreign variables are defined as follows

$$y_{it}^* = \sum_{j=0}^{N} w_{ij} y_{jt};\ p_{it}^* = \sum_{j=0}^{N} w_{ij} p_{jt};\ \Delta p_{it}^* = \sum_{j=0}^{N} w_{ij} \Delta p_{jt};\ x_{it}^* = \sum_{j=0}^{N} w_{ij} x_{jt};\ m_{it}^* = \sum_{j=0}^{N} w_{ij} m_{jt};$$

$$r_{it}^* = \sum_{j=0}^{N} w_{ij} r_{jt};\ e_{it}^* = \sum_{j=0}^{N} w_{ij} e_{jt};\ q_{it}^* = \sum_{j=0}^{N} w_{ij} q_{jt},$$

where w_{ij} is the share of country j in the trade (exports plus imports) of country i such that $w_{ii} = 0$ and $\sum_{j=0}^{N} w_{ij} = 1$. Following DHPS, the log real effective exchange rate, re_{it}, is defined as $ee_{it} + p_{it}^* - p_{it} = \tilde{e}_{it} - \tilde{e}_{it}^*$, where ee_{it} represents the nominal effective exchange rate defined as $\sum_{j=0}^{N} w_{ij} e_{ijt}$. Further details relating to the construction of the dataset may be found in the Data Appendix.

For countries $i = 1, 2, \ldots, 20$,[3] the CVARX* models include the following variables

$$\boldsymbol{x}_{it} = (re_{it}, r_{it}, im_{it}, ex_{it}, q_{it}, \Delta p_{it}, y_{it})' \quad \text{and} \quad \boldsymbol{x}_{it}^* = (p_t^o, r_{it}^*, q_{it}^*, \Delta p_{it}^*, y_{it}^*)'$$

while for countries $i = 21, 22, \ldots, 24$, we have

$$\boldsymbol{x}_{it} = (re_{it}, r_{it}, im_{it}, ex_{it}, \Delta p_{it}, y_{it})' \quad \text{and} \quad \boldsymbol{x}_{it}^* = (p_t^o, r_{it}^*, q_{it}^*, \Delta p_{it}^*, y_{it}^*)'$$

and for Saudi Arabia ($i = 25$) we have

$$\boldsymbol{x}_{25t} = (re_{25t}, im_{25t}, ex_{25t}, \Delta p_{25t}, y_{25t})' \quad \text{and} \quad \boldsymbol{x}_{25t}^* = (p_t^o, r_{25t}^*, q_{25t}^*, \Delta p_{25t}^*, y_{25t}^*)'.$$

The reduced domestic variable sets for these five countries are necessitated by the lack of reliable data. The omission of ex_{it}^* and im_{it}^* from the set of weakly exogenous foreign variables in all cases reflects the fact that the total imports (exports) of country i will be approximately equal to its trade-weighted foreign exports (imports) in a model such as ours with considerable global coverage. Finally, the US model contains the following variables

$$\boldsymbol{x}_{0t} = (p_t^o, r_{0t}, im_{0t}, ex_{0t}, q_{0t}, \Delta p_{0t}, y_{0t})' \quad \text{and} \quad \boldsymbol{x}_{0t}^* = (\tilde{e}_{0t}^*, \Delta p_{0t}^*, y_{0t}^*).$$

[3] See Table 1 for the country order.

The US is considered the reference country in line with DdPS. It is thus assumed that its exchange rate is determined in the remaining N country-specific models representing the rest-of-the-world in the GVAR model; hence the exclusion of re_{0t} from $\boldsymbol{x}_{0t}$ and the inclusion of $\tilde{e}^*_{0t}$ in $\boldsymbol{x}^*_{0t}$. Moreover, following DdPS, r^*_{0t} and q^*_{0t} are not included among the set of weakly exogenous variables as they are unlikely to be weakly exogenous in practice due to the dominant role of the US within the world economy. Similarly, p^o_t is treated as endogenous to the US.

2.2 Global Modelling

The first step in constructing the GVAR model is to collect the $(m+1) \times 1$ vector of the intermediate global variables (where $m = \sum_{i=0}^{N} m_i$)

$$\tilde{\boldsymbol{x}}_t = \left(\tilde{\boldsymbol{x}}'_{0t}, \tilde{\boldsymbol{x}}'_{1t}, ..., \tilde{\boldsymbol{x}}'_{Nt}\right)',$$

where

$$\tilde{\boldsymbol{x}}_{0t} = \left(\tilde{e}_{0t}, p^o_t, r_{0t}, m_{0t}, x_{0t}, q_{0t}, \Delta p_{0t}, y_{0t}\right)', \;\; \tilde{\boldsymbol{x}}_{it} = \left(\tilde{e}_{it}, r_{it}, m_{it}, x_{it}, q_{it}, \Delta p_{it}, y_{it}\right)'.$$

It follows that the $\boldsymbol{z}_{it}$'s for each country-specific model can be rewritten as

$$\boldsymbol{z}_{it} = \boldsymbol{W}_i \tilde{\boldsymbol{x}}_t, \;\; i = 0, 1, ..., N, \tag{6}$$

where the $\boldsymbol{W}_i$'s are $(m_i + m^*_i) \times (m+1)$ link matrices defined in terms of bilateral trade-weights retrieved from the IMF's DOTS database. The construction of the link matrices will be discussed in detail below. It is now straightforward to re-write (3) in stacked form as

$$\boldsymbol{H}_0 \tilde{\boldsymbol{x}}_t = \boldsymbol{h}^*_0 + \boldsymbol{h}_1 t + \boldsymbol{H}_1 \tilde{\boldsymbol{x}}_{t-1} + \boldsymbol{H}_2 \tilde{\boldsymbol{x}}_{t-2} + \boldsymbol{u}_t, \tag{7}$$

where

$$\underset{m\times(m+1)}{\boldsymbol{H}_0} = \begin{pmatrix} \boldsymbol{A}_{00}\boldsymbol{W}_0 \\ \boldsymbol{A}_{10}\boldsymbol{W}_1 \\ \vdots \\ \boldsymbol{A}_{N0}\boldsymbol{W}_N \end{pmatrix}; \;\; \underset{m\times(m+1)}{\boldsymbol{H}_1} = \begin{pmatrix} \boldsymbol{A}_{01}\boldsymbol{W}_0 \\ \boldsymbol{A}_{11}\boldsymbol{W}_1 \\ \vdots \\ \boldsymbol{A}_{N1}\boldsymbol{W}_N \end{pmatrix}; \;\; \underset{m\times(m+1)}{\boldsymbol{H}_2} = \begin{pmatrix} \boldsymbol{A}_{02}\boldsymbol{W}_0 \\ \boldsymbol{A}_{12}\boldsymbol{W}_1 \\ \vdots \\ \boldsymbol{A}_{N2}\boldsymbol{W}_N \end{pmatrix},$$

$$\boldsymbol{h}_0^* = \begin{pmatrix} \boldsymbol{h}_{00}^* \\ \boldsymbol{h}_{10}^* \\ \vdots \\ \boldsymbol{h}_{N0}^* \end{pmatrix};\ \boldsymbol{h}_1 = \begin{pmatrix} \boldsymbol{h}_{01} \\ \boldsymbol{h}_{11} \\ \vdots \\ \boldsymbol{h}_{N1} \end{pmatrix};\ \boldsymbol{u}_t = \begin{pmatrix} \boldsymbol{u}_{0t} \\ \boldsymbol{u}_{1t} \\ \vdots \\ \boldsymbol{u}_{Nt} \end{pmatrix}.$$

DHPS and GNS note that the omission of $\tilde{e}_{0t}$ from the US variables coupled with its inclusion in $\tilde{\boldsymbol{x}}_t$ necessitates the imposition of a further restriction in order to achieve a unique solution for $\tilde{\boldsymbol{x}}_t$ on the basis of the country-specific models. This additional restriction is derived from the definition of the US\$ exchange rate *vis-à-vis* the US\$. Hence, $e_{0t} = 0$ which implies that $\tilde{e}_{0t} = -p_{0t}$. Therefore, we may define the $m \times 1$ vector of global variables as

$$\tilde{\boldsymbol{x}}_t = \left(\mathring{\boldsymbol{x}}'_{0t}, \tilde{\boldsymbol{x}}'_{1t}, ..., \tilde{\boldsymbol{x}}'_{Nt}\right)',\ \mathring{\boldsymbol{x}}_{0t} = (p_t^o, r_{0t}, m_{0t}, x_{0t}, q_{0t}, p_{0t}, y_{0t})'.$$

The implication of this final restriction is that while we are solving for price-level inflation in countries $i = 1, ..., N$, we are solving for the price-level itself in the US. This necessitates the following transformation

$$\tilde{\boldsymbol{x}}_t = \boldsymbol{S}_0 \boldsymbol{x}_t - \boldsymbol{S}_1 \boldsymbol{x}_{t-1}, \tag{8}$$

where $\boldsymbol{S}_0$ and $\boldsymbol{S}_1$ are $(m+1) \times m$ selection matrices of the following form

$$\boldsymbol{S}_0 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & -1 & 0 & \mathbf{0} \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \boldsymbol{I}_{m-m_0} \end{pmatrix},\ \boldsymbol{S}_1 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0}_{m-m_0} \end{pmatrix}$$

The second order structural GVAR model may now be written as

$$\boldsymbol{F}_0 \boldsymbol{x}_t = \boldsymbol{h}_0^* + \boldsymbol{h}_1 t + \boldsymbol{F}_1 \boldsymbol{x}_{t-1} + \boldsymbol{F}_2 \boldsymbol{x}_{t-2} + \boldsymbol{F}_3 \boldsymbol{x}_{t-3} + \boldsymbol{u}_t, \tag{9}$$

where $\boldsymbol{F}_0 = \boldsymbol{H}_0 \boldsymbol{S}_0$, $\boldsymbol{F}_1 = \boldsymbol{H}_1 \boldsymbol{S}_0 + \boldsymbol{H}_0 \boldsymbol{S}_1$, $\boldsymbol{F}_2 = \boldsymbol{H}_2 \boldsymbol{S}_0 - \boldsymbol{H}_1 \boldsymbol{S}_1$, and $\boldsymbol{F}_3 = -\boldsymbol{H}_2 \boldsymbol{S}_1$.

The reduced-form GVAR is obtained by pre-multiplying throughout by $\boldsymbol{F}_0^{-1}$ yielding:

$$\boldsymbol{x}_t = \boldsymbol{g}_0^* + \boldsymbol{g}_1 t + \boldsymbol{G}_1 \boldsymbol{x}_{t-1} + \boldsymbol{G}_2 \boldsymbol{x}_{t-2} + \boldsymbol{G}_3 \boldsymbol{x}_{t-3} + \boldsymbol{\varepsilon}_t, \tag{10}$$

where $\boldsymbol{G}_j = \boldsymbol{F}_0^{-1}\boldsymbol{F}_j$, $j = 1, 2, 3$, $\boldsymbol{g}_0^* = \boldsymbol{F}_0^{-1}\boldsymbol{h}_0^*$, $\boldsymbol{g}_1 = \boldsymbol{F}_0^{-1}\boldsymbol{h}_1$, and $\boldsymbol{\varepsilon}_t = \boldsymbol{F}_0^{-1}\boldsymbol{u}_t$. Although the model is estimated on a country-by-country basis, the shocks may be weakly correlated across countries. Specifically, it is assumed that $E\left(\boldsymbol{u}_{it}\boldsymbol{u}'_{jt}\right) = \boldsymbol{\Sigma}_{u,ij}$ for $t = t'$ and 0 otherwise. Global interactions take place through three distinct but interrelated channels: (i) direct dependence of $\boldsymbol{x}_{it}$ on $\boldsymbol{x}_{it}^*$ and its lagged values, (ii) dependence of the country-specific variables on common global exogenous variables such as the crude oil price, and (iii) non-zero contemporaneous dependence of shocks in country i on shocks in country j, measured via the cross country covariances, $\boldsymbol{\Sigma}_{u,ij}$. Finally, as shown by DdPS, the GVAR model admits both intra- and inter-country cointegration. Note that the cointegration properties of the individual country-specific models are preserved in GVAR and thus the mean-reverting features of the individual economies carry over to the world economy.

2.3 Link matrices

Careful construction of the link matrices used in (6) fundamentally underpins the GVAR framework. In GNS, the $\boldsymbol{W}_i$'s are defined as follows:

$$\underset{10\times 177}{\boldsymbol{W}_0} = \begin{pmatrix} \boldsymbol{R}_{00} & \boldsymbol{0}_{7\times 7} & \cdots & \boldsymbol{0}_{7\times 7} & \boldsymbol{0}_{7\times 6} & \cdots & \boldsymbol{0}_{7\times 6} & \boldsymbol{0}_{7\times 5} \\ \boldsymbol{0}_{3\times 8} & \boldsymbol{W}_{01} & \cdots & \boldsymbol{W}_{0,20} & \boldsymbol{W}_{0,21} & \cdots & \boldsymbol{W}_{0,24} & \boldsymbol{W}_{0,25} \end{pmatrix},$$

$$\underset{12\times 177}{\boldsymbol{W}_i} = \begin{pmatrix} \boldsymbol{R}_{i0} & \boldsymbol{R}_{i1} & \boldsymbol{R}_{i2} & \cdots & \boldsymbol{R}_{i,25} \\ \boldsymbol{W}_{i0} & \boldsymbol{W}_{i1} & \boldsymbol{W}_{i2} & \cdots & \boldsymbol{W}_{i,25} \end{pmatrix}, \; i = 1, ..., 25,$$

where

$$\boldsymbol{R}_{00} = \begin{bmatrix} \boldsymbol{0}_{7\times 1} & \boldsymbol{I}_7 \end{bmatrix}, \; \boldsymbol{R}_{i0} = \begin{bmatrix} -w_{i0} & \boldsymbol{0}_{1\times 7} \\ \boldsymbol{0}_{6\times 1} & \boldsymbol{0}_{6\times 7} \end{bmatrix}, \; i = 1, ..., 25,$$

$$\{\boldsymbol{R}_{ij}\}_{j=1}^{20} = \begin{Bmatrix} \begin{bmatrix} -w_{ij} & \boldsymbol{0}_{1\times 6} \\ \boldsymbol{0}_{6\times 1} & \boldsymbol{0}_{6\times 6} \end{bmatrix} & \text{if } j \neq i \\ \boldsymbol{I}_7 & \text{if } j = i \end{Bmatrix}, \; i = 1, ..., 25,$$

$$\{\boldsymbol{R}_{ij}\}_{j=21}^{24} = \begin{Bmatrix} \begin{bmatrix} -w_{ij} & \boldsymbol{0}_{1\times 5} \\ \boldsymbol{0}_{6\times 1} & \boldsymbol{0}_{6\times 5} \end{bmatrix} & \text{if } j \neq i \\ \boldsymbol{I}_6 & \text{if } j = i \end{Bmatrix}, \; i = 1, ..., 25,$$

$$\boldsymbol{R}_{i,25} = \left\{ \begin{array}{cc} \begin{bmatrix} -w_{i,25} & \mathbf{0}_{1\times 4} \\ \mathbf{0}_{6\times 1} & \mathbf{0}_{6\times 4} \end{bmatrix} & \text{if } i \neq 25 \\ \boldsymbol{I}_5 & \text{if } i = 25 \end{array} \right\},$$

$$\{\boldsymbol{W}_{0j}\}_{j=1}^{20} = \begin{bmatrix} w_{0j} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & w_{0j} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & w_{0j} \end{bmatrix},$$

$$\{\boldsymbol{W}_{0j}\}_{j=21}^{24} = \begin{bmatrix} w_{0j} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & w_{0j} & 0 \\ 0 & 0 & 0 & 0 & 0 & w_{0j} \end{bmatrix}, \ \boldsymbol{W}_{0,25} = \begin{bmatrix} w_{0,25} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & w_{0,25} & 0 \\ 0 & 0 & 0 & 0 & w_{0,25} \end{bmatrix},$$

and for $i = 1, ..., 25$,

$$\boldsymbol{W}_{i0} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & w^{*}_{i0} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & w^{**}_{i0} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & w_{i0} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{i0} \end{bmatrix}, \ \{\boldsymbol{W}_{ij}\}_{j=1}^{20} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & w^{*}_{ij} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & w^{**}_{ij} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & w_{ij} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & w_{ij} \end{bmatrix},$$

$$\{\boldsymbol{W}_{ij}\}_{j=21}^{24} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & w^{*}_{ij} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & w_{ij} & 0 \\ 0 & 0 & 0 & 0 & 0 & w_{ij} \end{bmatrix}, \ \boldsymbol{W}_{i,25} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & w_{i,25} & 0 \\ 0 & 0 & 0 & 0 & w_{i,25} \end{bmatrix}.$$

The w_{ij}'s denote the weight of country i in the trade of country j. Similarly, the w^{*}_{ij}'s denote the weight of country i in the trade of country j after adjusting appropriately for the lack of Saudi interest rate data. Finally, the w^{**}_{ij}'s represent the weight of country i in the trade of country j adjusted to account for the omission of the stock index for China, Indonesia, Peru and Turkey and Saudi Arabia. By construction, $\sum_{j=0}^{N} w_{ij} = \sum_{j=0}^{N} w^{*}_{ij} = \sum_{j=0}^{N} w^{**}_{ij} = 1$, and $w_{ii} = w^{*}_{ii} = w^{*}_{ii} = 0 \ \forall i$.

As in DdPS, GNS define the 26×26 trade-weight-based link matrices using bilateral trade averages reported in the IMF's DOTS database over the period 1999-2001. Preliminary estimation results using trade averages defined over different windows and also using time-varying trade weights yield qualitatively similar results; therefore the weighting scheme used in DdPS is retained to maintain closer comparability with their results.

2.4 Dynamic analysis of the GVAR model

While the focus of GNS is on scenario-based probabilistic forecasting, our focus here is on the analysis of generalised impulse response functions (GIRFs) and generalised forecast error variance decompositions (GFEVDs). The order-invariance of the generalised approach to dynamic analysis is important in the context of GVAR models, as deriving a robust structural factorisation of the contemporaneous matrix would be highly challenging given the dimensionality of the system, as would achieving an uncontroversial Wold-causal ordering of the global variables. Therefore, we will abstract from the case of structurally identified shocks herein.

DHPS discuss the extension of the standard tools of dynamic analysis in VAR to the global VAR context. The starting point is the MA(∞) representation of the GVAR model, (10)

$$\boldsymbol{x}_t = \boldsymbol{d}_t + \sum_{j=0}^{\infty} \boldsymbol{B}_j \boldsymbol{\varepsilon}_{t-j}, \tag{11}$$

where $\boldsymbol{d}_t$ represents the deterministic component of $\boldsymbol{x}_t$ and $\boldsymbol{B}_j$ is evaluated recursively as follows

$$\boldsymbol{B}_j = \boldsymbol{G}_1 \boldsymbol{B}_{j-1} + \boldsymbol{G}_2 \boldsymbol{B}_{j-2} + \boldsymbol{G}_3 \boldsymbol{B}_{j-3},\ j = 1, 2, \text{with } \boldsymbol{B}_0 = \boldsymbol{I}_m,\ \boldsymbol{B}_j = \boldsymbol{0} \text{ for } j < 0.$$

The generalised impulse response function (GIRF) representing the time profile of the effect of a one unit (one standard error) shock to the ℓth element of $\boldsymbol{x}_t$ on the jth element of $\boldsymbol{x}_t$ is given by

$$GIRF\left(x_{jt}; u_{\ell t}, n\right) = \frac{\boldsymbol{e}_j' \boldsymbol{B}_n \boldsymbol{F}_0^{-1} \boldsymbol{\Sigma}_u \boldsymbol{e}_\ell}{\sqrt{\boldsymbol{e}_\ell' \boldsymbol{\Sigma}_u \boldsymbol{e}_\ell}},\ n = 0, 1, 2, ...,\ j, \ell = 1, ..., m. \tag{12}$$

where $\boldsymbol{e}_j$ is an $m \times 1$ selection vector whose jth element is equal to unity with zeros elsewhere (similarly for $\boldsymbol{e}_\ell$). In the GVAR model, this expression may be used to compute the effects of shocking any chosen endogenous variable on any or all of the global endogenous variables at any desired horizon.[4]

Forecast error variance decomposition in the context of VAR models is typically performed on a set of orthogonalised shocks derived from Choleski decomposition of the variance matrix,

[4]Note that the GIRF of a unit shock to the US price-level can be converted to that of a shock to US inflation simply by first-differencing.

where the contribution of the jth orthogonalised innovation to the mean squared error of the n-step ahead forecast is computed (e.g. Diebold and Yilmaz , 2009). However, in the context of a GVAR model involving multiple variables for multiple countries, it is generally infeasible to find a causal ordering such that the shocks across countries and variables can be assumed to be orthogonal. We therefore have recourse to GFEVDs, which are order-invariant and are computed by conditioning on non-orthogonalised shocks, u_{jt}, u_{jt+1},..., u_{jt+n} for $j = 1, ..., m$. The GFEVD representing the proportion of the n-step ahead forecast error variance of the ℓth element of $\boldsymbol{x}_t$ accounted for by the innovation in the jth element of $\boldsymbol{x}_t$ is written as

$$GFEVD\left(x_{\ell t}; u_{jt}, n\right) = \frac{\sigma_{u,jj}^{-1} \sum_{h=0}^{n} \left(\boldsymbol{e}_{\ell}' \boldsymbol{B}_h \boldsymbol{F}_0^{-1} \boldsymbol{\Sigma}_u \boldsymbol{e}_j\right)^2}{\sum_{h=0}^{n} \boldsymbol{e}_{\ell}' \boldsymbol{B}_h \boldsymbol{F}_0^{-1} \boldsymbol{\Sigma}_u \boldsymbol{F}_0^{-1\prime} \boldsymbol{B}_h' \boldsymbol{e}_{\ell}}, \; n = 0, 1, 2, ..., \; \ell = 1, ..., m, \qquad (13)$$

It is important to note that the non-diagonality of $\boldsymbol{\Sigma}_u$ implies that the elements of $GFEVD\left(x_{\ell t}; u_{jt}, n\right)$ need not sum to unity across j. Hence, we follow Diebold and Yilmaz (2011) and define the *normalized* GFEVD as

$$\eta_{\ell j} = \frac{GFEVD\left(x_{\ell t}; u_{jt}, n\right)}{\sum_{\ell=1}^{m} GFEVD\left(x_{\ell t}; u_{jt}, n\right)}$$

from which it follows trivially that

$$\sum_{\ell=1}^{m} \eta_{\ell j} = 1 \text{ and } \sum_{j=1}^{m} \sum_{\ell=1}^{m} \eta_{\ell j} = m$$

One significant benefit of normalizing such that the sum of the forecast error variance shares of each variable is equal to 100% is that it eases the interpretation of the GFEVDs and improves the robustness of the analysis where large scale differences are present between variances.

3 Preliminary Analysis

The GNS model is estimated over the period 1980Q2–2007Q2 for the set of 33 countries (26 regions) identified in Table 1 (details of the dataset and its construction may be found in the Appendix). Tables 2 and 3 provide summary statistics of real output growth, inflation and the balance of trade, which may be considered the three key macroeconomic indicators in the dataset. A number of well-known stylised facts are readily apparent in the data.

[Insert Tables 2 and 3 about here]

Firstly, it is apparent that the level and volatility of the average real output growth rate varies substantially across countries. The average real output growths of developed countries lie in the range 2-3.5% per annum (e.g. 3.05% for the U.S., 2.17% for the Eurozone, 2.58% for Japan, 2.57% for the UK, 2.76% for Canada and 3.26% for Australia). The emerging economies of Asia have enjoyed considerably faster growth, typically between 5 and 7% (e.g. 6.43% for Korea, 5.97% for India, 6.76% for Singapore and 5.69% for Thailand). The two exceptions are China with the highest growth rate of 9.48%, and the Philippines exhibiting slow growth at just 2.99%. Among the remaining countries, Turkey and Chile have relatively high growth rates of approximately 4.4% per annum, compared to an average of just 2%. The real output growths of developed countries are relatively stable, with standard deviations between 2% and 4%, while standard deviations between 6% and 12% typify the emerging and developing countries. Interestingly, China has enjoyed the most rapid growth (9.48%) in conjunction with volatility comparable to that of a developed economy (3.16%).

Historical accounts of inflation among the 26 countries/regions are summarised in Table 2. The most striking feature is that average rates of inflation in almost all countries are considerably higher than those experienced in recent years. This observation is often attributed to the widespread adoption of inflation-targeting monetary policy regimes in recent years. The developed economies have the lowest and most stable inflation rates on average, ranging from 2% to 5% (e.g. 3.45% for the US, 3.41% for Eurozone, 0.99% for Japan and 4.18% for the UK). The Japanese figure is somewhat misleading, deriving largely from the post-1990 deflationary era. The emerging Asian economies have experienced slightly higher average inflation rates, mostly of the order of 5-8%. In particular, the figures for China and Korea are approximately 5% and that of India is 7.54%. Singapore and Saudi Arabia are notable for their low inflation rates, at 1.67% and 0.51%, respectively. The Latin American countries and Turkey suffered hyperinflation during the sample period which are both high and extremely volatile. Specifically, the average inflation rates are 97.43% for Brazil, 70.19% for Argentina, 66.93% for Peru and 40.10% for Turkey. Inflation peaked in Argentina at 759.22% in 1989Q3, 622.61% in Brazil in 1990Q1 and 856.53% in 1990Q3 in Peru.

Table 3 summarises the real export and import performance of countries. Similar to the patterns observed for real output growth and inflation, the industrialised countries have experienced lower and more stable average export and import growth, typically in the range 1-3%.

Emerging and developing economies exhibit higher but more volatile growth rates. For example, the average export and import growth rates are 16.13% and 14.02% for China, 9.02% and 8.56% for India, 8.18% and 6.97% for Korea, 10.01% and 8.23% for Thailand, and 9.70% and 7.78% for Turkey. Table 3 also demonstrates the often large and persistent current account deficits that characterise many of the more developed countries. In particular, the US, UK, Australia, and New Zealand experience average growth rates of trade deficit of 1.49%, 1.09%, 0.68% and 0.80%, respectively. However, this trend is not universal, with the Eurozone, Japan, Norway, Sweden and Switzerland all experiencing average growth rates of trade surplus of 0.50%, 0.98%, 1.66%, 1.05% and 0.96%, respectively. Almost all of the emerging and developing economies enjoy trade surpluses. China, Korea and Singapore have relatively high growth rates of trade surplus of 2.11%, 1.20% and 1.26%, respectively, reflecting their export-led growth strategies.

3.1 Pre-Testing Results

GNS verify that the overwhelming majority of the series used in estimation follow non-stationary $I(1)$ processes. Furthermore, GNS find that the hypothesis that the foreign regressors are weakly exogenous cannot generally be rejected at the 5% level. These findings are not surprising but they are important, as they underpin the cointegrating GVAR model. Of more interest, however, are the structural break tests conducted in GNS. Given our emphasis on intertemporal effects and our belief that many of the World's economies have been subject to significant shocks that may have altered the behaviour of their core variables as well as the relationships among them, testing for structural breaks is of paramount importance. Where the impact of a break is substantial (e.g. the 1997 Asian crisis), the choice of whether or not to include break dummies in the country-specific models will have a profound effect on both the cointegrating relationships in the model and its performance in terms of dynamic analysis. Balancing this argument, however, one must also bear in mind that the impact of structural breaks may be attenuated to some degree in the global system due to co-breaking behaviour.

In GNS, we adopt a simple and pragmatic approach to structural break testing based on CUSUM tests of the country-specific VECM models. The main limitation of the treatment of structural breaks is that each country-specific model allows for only a single one-time permanent intercept shift that occurs at the same time for all of the domestic endogenous variables in that country. Therefore, it is necessary to interpret the statistical evidence of breaks derived from the formal testing procedure with care and select 'consensus' break points which may be considered to be significant events which have had repercussions for the entire economy. Table 1 summarises the timing and probably cause of our selected structural breaks. GNS find substantial support for a break in 1997Q3/4 for the South-East Asian bloc relating to the financial crisis (in particular inflation and output show a noticeable perturbation).[5] Similarly, the South American economies generally exhibit striking breaks associated with dollarisation (interest rates, exchange rates and inflation are typically profoundly effected). Careful analysis also suggests that the departure of the UK from the ERM had significant repercussions for the domestic economy as of 1992Q4 and that the real-estate and stock-market crash in Japan caused a break at 1990Q1. Lastly, the composite Eurozone economy reacts noticeably to the introduction of the Euro in 1999Q1, with imports, exports and the exchange rate showing the strongest response.

4 Generalized Impulse Response Analysis

As a first step in our analysis of the international linkages of the Korean macroeconomy, we consider the effect of a number of economically interesting scenarios by means of generalized impulse response analysis. More specifically, we consider an oil price shock, a US interest rate shock, a US stock market shock, a Chinese inflationary shock and a Korean interest rate shock. All the shocks are of one standard error in magnitude. Where possible, comparisons will be drawn between our findings and the results derived from Shin's (2009) national model. In general, one would expect to see some differences between the results of the two models for a variety of reasons. Firstly, the models are estimated on different datasets.[6] Secondly, Shin considers only the three shocks to oil price, foreign and domestic monetary policy, and reports structural as opposed to generalised impulse response functions under the assumption that $r = 5$ rather than $r = 4$, as is the case here. Finally, the GVAR model accounts for inter-country linkages in a sophisticated manner of which the national model is inherently incapable.

[5]Notice that in the Korean national model developed by Shin (2009), a one-time permanent intercept shift is included at 1997Q4.

[6]Shin (2009) defines $\boldsymbol{x}_t = (e_t, r_t, \Delta p_t, y_t, pps_t, h_t)'$ and $\boldsymbol{x}_t^* = (p_t^o, r_t^*, y_t^*)'$, where h_t is the log of the money-output ratio and $pps_t = p_t - p_t^*$ is the relative price. An additional difference lies in the construction of foreign variables. In particular, r_t^* is proxied by the US interest rate while both p^* and y_t^* are constructed using the OECD aggregate measures.

4.1 Oil Price Shock

Figure 1 shows the effect of a positive oil price shock on each of the Korean domestic variables, as well as the trade balance defined as $TB = X - M$. Inflation increases immediately as one might expect, although it decreases in the second quarter before increasing again in the third quarter. At longer horizons, the inflationary response becomes negative. This negative long-run response may, in turn, result from the positive response of the interest rate to the shock, which is suggestive of early monetary tightening by the Bank of Korea to prevent higher oil prices leading to rising inflation. These findings contrast somewhat with those of Shin (2009), where an oil price shock is found to have a negligible effect on inflation and interest rates at all horizons. One interesting possibility is that the Korean government's history of intervening in petroleum markets may have insulated the economy from the expected inflationary effects of oil price rises.

As expected, the shock has a strong negative effect on output, both on impact and in the medium- to long-run, reaching a trough after 8 quarters. A similar result is achieved by Shin (2009). Similarly, the stock market response is strongly negative reflecting a generalised reduction in the expected discounted profits of Korean firms. The import response is initially positive reflecting the higher cost of oil imports in the short-term but then decreases and settles at a negative value in the long-run. This pattern suggests that oil demand in Korea is somewhat elastic but that Korean households and firms adjust their resource consumption gradually. Meanwhile, the export response is negative throughout. Furthermore, since the response of exports dominates that of imports in absolute value, the trade balance deteriorates at all horizons. Finally, the real exchange rate decreases (i.e. appreciates) on impact before gradually depreciating and settling at a weaker value in the long-run. This long-run depreciation is again comparable with the result from Shin's national CVAR model.

[Insert Figure 1 about here]

4.2 US Interest Rate Shock

Figure 2 plots the impulse responses of the Korean domestic variables with respect to a positive US interest rate shock (indicating the US contractionary monetary policy). The US monetary shock seems to have very small impacts on domestic interest rate, output and inflation in comparison with the effects on the nominal exchange rate and other domestic variables. As expected, however, the Korean interest rate responds positively following the shock given the pre-eminent role of US securities in global financial markets. The shock is associated with a gradual appreciation of the real exchange rate which is maintained in the long-run. This pattern is qualitatively consistent with that documented by Shin, in which he also notes that the decreases in relative price and domestic real money balance might help explain the appreciation. It is likely that this appreciation exerts upward pressure on imports and downward pressure on exports, and this provides a plausible explanation of the observed negative response of the trade balance following the shock. Meanwhile, output growth falls in the short- to medium-term, reflecting the close linkage between exports and economic activity in the Korean macroeconomy. Interestingly, the effect of the shock on inflation is positive at all horizons. This finding contrasts with Shin (2009) who finds that the US monetary shock will lower inflation rates at all horizons, albeit negligibly small. On one hand, this may simply be a manifestation of the well-known empirical price puzzle. On the other hand, it could be at least partially the result of cost-push inflationary pressures if leveraged firms pass a significant proportion of the cost increases resulting from higher domestic and, especially, foreign interest rates on to their customers. Finally, the response of the stock market is also positive at all horizons. It is a widely-held belief that equity prices respond negatively to interest rate innovations as the latter increases the discount factor applied to future earnings. However, stock markets may in fact record gains following interest rate hikes if investors move from bonds to equity as higher yields depress bond prices.

[Insert Figure 2 about here]

4.3 US Stock Market Shock

Figure 3 shows the impact of a positive US stock market shock. The Korean stock market response is relatively strong and positive on impact before it intensifies and reaches a peak after 5 quarters, after which it gradually eases toward a long-run positive value. The positive response of the KOSPI on impact reflects the sensitivity of Korean financial markets to conditions in the major world markets. This is a clear manifestation of the profound global financial linkages that have developed in the era of globalisation. However, the strengthening of the KOSPI's response over the following four quarters is also suggestive of significant real linkages between the US and Korea deriving from the strong bilateral trade links between the two countries coupled with Korea's export-oriented growth strategy.

Considerable evidence of these trade linkages may be found in the responses of output, inflation, exports and imports. In all cases, we observe a positive impact response followed by convergence to a positive long-run value. Interestingly, the GIRFs for imports and exports peak at 7 quarters while output growth peaks at 5 quarters, roughly coinciding with the peak equity response. Since the growth in imports exceeds that in exports, the trade balance actually deteriorates somewhat following the shock. Meanwhile, the interest rate response is initially negligible before gradually increasing and settling at a long-run positive value, reflecting the policy response to elevated inflationary pressure. Finally, the real exchange rate experiences a mild appreciation consistent with the higher level of the interest rate.

[Insert Figure 3 about here]

4.4 Chinese Inflationary Shock

Figure 4 plots the impulse responses associated with elevated Chinese inflationary pressure. Given the growing importance of China within the world economy and the close trading relationship between Korea and China, such a shock may be expected to exert a significant influence on the Korean macroeconomy and our results confirm this hypothesis. Inflation increases sharply following the shock and further overshoots into the second quarter before settling at a value close to zero in the long-run. Meanwhile, the interest rate response is suggestive of anti-inflationary monetary policy as the interest rate increases after a modest lag and is maintained at a higher level into the long-run. The maintenance of higher domestic interest rates presumably contributes to the observed appreciation of the Korean Won following the shock. In turn, the strengthening of the Won is likely to explain a large proportion of the observed decline in real exports. Meanwhile, real imports also decline. This probably reflects a combination of factors, including reduced demand for imported intermediate inputs used by exporting industries and the higher price of imported goods from China (and other countries to which the Chinese inflation has been passed on). Interestingly, despite the deterioration in the trade balance, the shock exerts a positive influence on both output growth and the stock market in the short- to medium-term.

[Insert Figure 4 about here]

4.5 Korean Interest Rate Shock

Figure 5 plots the impulse responses following a positive Korean interest rate shock. The response of inflation on impact is positive but thereafter a small negative response is observed.

Interestingly, the shock is found to exert an expansionary effect on real output. This is an unexpected finding but it is consistent with Shin (2009), who finds a positive output response for the first five quarters after the shock, and attributes this finding to the suboptimal conduct of domestic monetary policy in the years leading up to the Asian Financial Crisis.

The real exchange rate appreciates on impact and further overshoots in the second quarter before gradually converging to a stronger value in the long-run. This pattern closely matches that documented by Shin, which he notes is generally consistent with Dornbusch's (1976) overshooting model, which predicts a large initial appreciation following a monetary tightening followed by subsequent depreciation to its long-run level. The response of real imports is positive on impact reflecting the strengthening of the Won, but it then turns negative from the second quarter. Meanwhile, the strengthening of the currency contributes to the negative response of real exports at all horizons. Overall, therefore, the response of the trade balance is also negative. Finally, the stock market contracts in the short- to medium-term before a significant positive response emerges in the long-run. This is consistent with Shin's (2009, p.222) observation that interest rates remained relatively high even in the boom phase before the crisis.

[Insert Figure 5 about here]

5 Forecast Error Variance Decomposition

In this Section, we seek to understand which global variables exert a dominant influence on a selection of key economic indicators for Korea by use of normalised GFEVDs. However, the GFEVDs derived from the basic GNS model are often somewhat distorted in the sense that the top 10 contributors to the forecast error variance for a given variable over a given horizon may be rather diversely distributed. For example, in the case of Korea, it is not uncommon to observe variables from relatively peripheral countries such as Argentina, Australia, Brazil, Canada, Chile, Malaysia, Mexico, Peru, Singapore, South Africa, Sweden and Thailand among the main contributors.

These results suggest that many of the off-diagonal blocks in Σ_u may be imprecisely estimated or statistically insignificant due to the relatively high dimensionality of the GVAR model. This is likely to be especially true of those blocks associated with small and/or developing countries and regions. A simple and parsimonious solution to this issue is to impose block diagonality in Σ_u, such that the global covariance matrix is defined as follows

$$\Sigma_u = \begin{bmatrix} \Sigma_{u,00} & 0 & \cdots & 0 \\ 0 & \Sigma_{u,11} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \Sigma_{u,NN} \end{bmatrix}$$

While this may at first glance seem to impose onerous restrictions on the degree to which international linkages are captured in the model, note that the direct impacts of the weighted average of the foreign variables have already been incorporated in the estimation of the country-specific VAR parameters. Therefore, in this Section, we report the results obtained using the block-diagonal covariance matrix.[7]

Figure 6 reports a simplified summary of the normalized GFEVDs for each of the Korean domestic variables. In each case, the normalized forecast error variance (FEV) is decomposed into four components as follows:

own the proportion of the variable's FEV explained by the variable itself

other_dom the proportion explained by the remaining domestic variables

oil the proportion explained by the oil price

foreign the proportion explained by all foreign variables excluding oil

A number of interesting patterns emerge. Firstly, the own contribution is typically dominant in the short horizon but its importance fades rapidly as the horizon increases. The only case where this pattern is noticeably less prevalent is the real exchange rate. Secondly, the combined contribution of oil and foreign variables increases markedly with the horizon in all cases except the interest rate (where it remains relatively constant throughout) and the real exchange rate (where it starts at a very high level and the decreases somewhat). Finally, the contribution of the oil price becomes very large in the case of real exports, equity prices and real output but plays a much less prevalent role in the remaining cases.

[Insert Figure 6 about here]

[7] Comprehensive tables of the generalised FEVDs derived from the GVAR model and orthogonalised and generalised FEVDs based on the country-specific models are available upon request. In future work it would be interesting to consider an intermediate case based on formal tests of cross-section dependence, but this is beyond the scope of the current paper.

Panel (a) of Figure 6 shows the time profile of our decomposition for the real exchange rate. The own contribution (i.e. the proportion of the real exchange rate FEV accounted for by the real exchange rate) starts at 22% at the one quarter horizon before gradually diminishing to 11% after twelve quarters. Meanwhile, the total contribution of the other domestic variables increases from 8% to 21% over the same time frame, with the most significant contributions coming from the stock market, the interest rate and real exports. The contribution of the oil price is small at all horizons, averaging just 1.75% over twelve quarters. The remainder of the FEV (totalling more than 50% at all horizons up to twelve quarters) is therefore accounted for by conditions in Korea's overseas trading partners. This is an intuitively pleasing finding in the case of a small, open and export-oriented economy such as Korea. Interestingly, Japanese real exchange rates, exports and imports are significant contributors to the FEV in the shorter horizons but their influence diminishes at longer horizons, being supplanted notably by Chinese and European variables. US output is also found to exert a non-negligible influence on the Korean real exchange rate, particularly at longer horizons.

Panel (b) reports the case of the interest rate. In this case, the own contribution decreases from 67% at the one quarter ahead horizon to just 9% after 12 quarters. Meanwhile, the equivalent values for the contribution of the remaining domestic variables are 6% and 61%. Overall, therefore, the total domestic contribution to the FEV remains remarkably constant at roughly 70% across all horizons. A plausible explanation of this finding is that it simply reflects the domestic focus of the Korean monetary policy. Once again, oil prices play a peripheral role, while the most important foreign contributors to the interest rate FEV are the US and European stock markets and Chinese inflation, each of which may be expected to influence Korean price level inflation in a relatively straightforward manner.

Panels (c) and (d) relate to real imports and real exports. In each case, we observe a significant own contribution at the one quarter ahead horizon of the order of 60%. This diminishes rapidly in both cases but more significantly for exports, where the own contribution after 12 quarters is just 5.5% as opposed to 23.5% for real imports. Meanwhile, the contribution of the other domestic variables is broadly similar, but is slightly larger on average in the case of real exports. The most important domestic variable for imports is inflation, while for exports it is the real exchange rate. Both results highlight the importance of relative purchasing power concerns for the trade variables. One interesting difference between the figures is the relative contribution of the oil price to the respective import and export FEVs. At shorter horizons, the contribution of the oil price is small or even negligible in both cases. However, while it remains fairly small for imports this is not true of exports where it reaches 20% after 12 quarters. As mentioned above, government intervention in energy markets may explain the relatively muted effect of the oil price on imports. Finally, the contribution of the non-oil foreign variables increases from approximately 10% at the one quarter horizon to roughly 50% after 12 quarters. The most important foreign contributors to the import FEV are US equity prices, output and prices, Chinese output and European equity prices. Similarly, the same three US macroeconomic variables account for the majority of non-oil foreign contributions to the export FEV.

Panel (e) shows results for the Korean stock market FEV. In this case, the own contribution declines smoothly from 58% to 21% after 12 quarters while the contribution of the other domestic variables remains relatively muted, averaging just 8% over the 12 quarter horizon. This suggests that domestic economic conditions do not exert a dominant influence on the performance of the KOSPI which, in turn, is suggestive of the index's rapid integration into the global financial system, especially after the IMF bailout program suffered during the Asian crisis period. The contribution of the oil price to the equity FEV is significant at all horizons, starting at 6% and climbing to 34% after 12 quarters. This clearly reflects the considerable energy intensity of economic activity in Korea coupled with its reliance on imported oil. Finally, the contribution of the non-oil foreign variables is substantial at all horizons and becomes the dominant influence on the equity FEV at the four quarter ahead horizon and beyond. The most important foreign variables are US equity prices, consumer prices, imports and exports, as well as European equity prices. Furthermore, Japanese equity prices play a non-negligible role at shorter horizons, accounting for more than 3% of the one quarter ahead equity FEV. These results suggest that not only is the KOSPI relatively insensitive to domestic economic conditions but it is highly sensitive to conditions in the World's dominant markets.

Panel (f) shows the results for inflation. The own contribution falls sharply from 61% at the one quarter ahead horizon to just 9% at the two quarter ahead horizon before it settles at roughly 16.5% in the longer horizons. The contribution of the other domestic variables grows substantially from 7% to 28% over the same time-frame. Interestingly, real imports are the most significant of the domestic variables (even including the own contribution) contributing 21% on average over 12 quarters. This suggests that import prices are a significant component of Korean price level inflation, a phenomenon which is likely to complicate the task of domestic macroeconomic management considerably. Interestingly, however, the contribution of the oil price is negligible at all horizons. This suggests that government intervention in the energy markets seems to have successfully limited the degree to which fluctuations in energy prices are passed through to the Korean economy. Finally, the non-oil foreign contribution is large, rising from 31% to 53% over the twelve quarter horizon. The most important foreign variables on average over 12 quarters are US equity prices, US output, Chinese inflation, the US price level, and European equity prices.

Turning to real output in Panel (g), we once again observe the familiar decline in the own contribution as the horizon rises. The contribution of the other domestic variables remains fairly constant between 13% and 24% across all horizons. As with the case of equity FEVs reported in panel (e), and for the same reasons, the contribution of oil price is considerable from the outset and grows substantially as the horizon increases, reaching 42.5% after 12 quarters. Finally, the non-oil foreign contribution is non-negligible, growing from 16% to 29% over 12 quarters, with the most important variables being the US price level, equity price and real imports. As before, this reflects the dominant position of the US among Korea's trading partners.[8]

Finally, Table 4 provides a crude summary of the key factors influencing various aspects of the Korean economy. Specifically, the table reports the three variables that account for the largest proportion of the FEV for each of the Korean domestic variables separately. As expected, the principle factors affecting the Korean economy are domestic conditions within Korea as well as financial conditions in the US and the European real exchange rate. When broadening the analysis to consider the top ten contributors rather than the top 3 (results are not reported here but full details are available on request) we find that they typically account for between 70% and 90% of the total FEV and that the most heavily represented nations are Korea, the US, the Eurozone, China and Japan, as expected. This seems intuitively plausible, and underscores our earlier contention that the results based on the block diagonal covariance matrix are preferable to those obtained under the unrestricted (non-diagonal) covariance matrix, where a far more diverse group of countries are represented.

[Insert Table 4 about here]

[8]The oil price impacts on growth and inflation will differ across different countries, depending upon their level of exposure and the market deepening. Given that the oil price hikes do not seem to fuel domestic inflation in Korea, especially over the longer horizons as discussed in Subsection 4.1, however, it is worth further investigating the channel through which oil prices impact output and equity prices in Korea.

6 Concluding Remarks

This paper has analysed the international linkages of the Korean macroeconomy within a global framework using the GVAR model developed by GNS. The GNS model considers the same group of 33 countries (26 regions) considered by DdPS but extends their analysis by incorporating trade variables and explicitly modelling intertemporal structural instability by the inclusion of country-specific intercept shift dummies. Accounting for structural instability in this way is vital when studying countries affected by significant and long-lasting economic perturbations such as the 1997 Asian currency crisis. In this sense, the GNS model is therefore ideally suited to our application. Furthermore, it follows that any analysis of regional and global linkages will benefit from being situated within a truly global framework such as the GNS GVAR model. Indeed, given its ability to explicitly model the nature of foreign influences on a sovereign state or economic block, the GVAR framework represent a singularly powerful tool for the analysis of bilateral and multilateral economic interconnections.

In the first stage of our analysis, we considered a selection of GIRFs representing the expected effect of a variety of economically interesting shocks on the Korean economy. Focusing on a small number of GIRFs with respect to an oil price shock, a US interest rate shock, a US stock market shock, a Chinese inflationary shock and a domestic interest rate shock, our results reveal a number of interesting phenomena. Firstly, our results indicate that there is a schism between the sensitivity of the real and nominal sides of the Korean economy in relation to oil prices, with real variables generally responding much more strongly. We attribute this finding to government intervention in the energy markets in the earlier years of our sample. Secondly, we find little evidence that interest rate hikes (whether domestic or foreign) exert significant disinflationary or contractionary effects on the Korean economy; rather, we find evidence to the contrary. In particular, we find that the common dictum that equity prices respond inversely to interest rates does not seem to hold in Korea. Thirdly, we find that the performance of the real economy and the stock market is strongly influenced by the performance of the US economy, and also to a lesser degree by the European, Chinese and Japanese economies. We conclude that these strong linkages will complicate the task of domestic economic management faced by the central bank and the government.

In the second stage of our analysis, we analyse the main contributors to the nomralized generalized forecast error variance of the Korean domestic variables in our global system. Importantly, we find it necessary to impose block-diagonality of the global covariance matrix to refine our analysis and to filter out the distortions arising from imprecise estimation of some of the non-diagonal blocks under free estimation. We employ a simple aggregation of the GFEVDs which yields an estimate of a variable's own contribution to its variance share, the contribution of the other domestic variables, the contribution of the oil price and the contribution of the non-oil foreign variables. Our analysis reveals a number of stylised findings. Firstly, the own contribution dominates over a short horizon after which the foreign variables (including oil) typically becomes the dominant force. Secondly, we find that the interest rate is relatively insensitive to conditions overseas except to the extent that it is significantly effected by the real exchange rate of the Korean Won. Thirdly, the oil price exerts a powerful influence on real exports, equity prices and real output, but not generally in the remaining cases. At an over-arching level, our results suggest that the major sources of overseas influence on the Korean economy are the core macroeconomic variables for the US, the equity indices in the US, the Eurozone and Japan, and the macroeconomic variables for China, most notably inflation. This array of linkages further strengthens our earlier conclusion about the difficulty of successful domestic economic management in Korea.

7 Data Appendix

Variables used in this paper include y ($ln(Y_{it}/CPI_{it})$, real GDP), p ($ln(CPI_{it})$, consumer price index), q ($ln(Q_{it}/CPI_{it})$, real equity price index), e ($ln(E_{it})$, nominal exchange rate in terms of the US Dollar), r ($(0.25 \times ln(1 + R_{it}/100))$, short–term interest rate), x ($ln(\frac{EXPORT_{it} \times E_{it}}{CPI_{it}})$, real exports), m ($ln(\frac{IMPORT_{it} \times E_{it}}{CPI_{it}})$, real imports) and p^o ($ln(POIL_{it})$, nominal spot oil price).

GDP: Nominal GDP series for 33 countries are taken from the International Monetary Fund (IMF)F's International Financial Statistics (IFS), Series 90BVRZF (Index, 2000 = 100). Where quarterly data were not available, quarterly series were generated from annual series using the interpolation procedure of DdPS (see their Supplement A for details of the interpolation procedure). Specifically, the interpolated series were used throughout the sample period for China and Saudi Arabia and during the following sub-periods: 1980-1989 for Argentina, 1980-1990 for Brazil, 1980-1996 for India, 1980-1982 for Indonesia, 1980-1987 for Malaysia, 1980-1989 for Philippines, 1980-1992 for Thailand, 1980-1986 for Turkey. In these countries, quarterly data were available for the remainder of the sample period. Where data were not available, the IFS series were completed by data from other sources: Datastream, OECD, or extrapolated growth rates (using the average growth rate of three previous years). The series for Singapore were completed by Datastream data, while the series for Brazil, India and the UK were completed using OECD data. The series for Argentina, Austria, Belgium, Brazil, Chile, Finland, India, Indonesia, Korea, Malaysia, Mexico, Norway, Peru, Philippines, Sweden, Thailand, and Turkey were seasonally adjusted using the US Census Bureau's X12 routine.

The Consumer Price Index: For most of the 33 countries, the data were taken from IFS Series 64.ZF (Index, 2005 = 100), except for China, Finland and Germany. The series for China (seasonally adjusted from 1987Q1–2007Q2) and Germany (1980Q1–2007Q2) were provided by the Bank of Korea. The series for China was completed by IFS Series 64.XZF. Meanwhile, Finland's price index was collected from IFS Series 63EY.ZF.

Nominal Exchange Rate: IFS Series RF.ZF (national currency per US$) were used for all countries. The Eurozone's nominal exchange rate was constructed from the series of 8 member countries (Austria, Belgium, France, Finland, Germany, Italy, Spain, and Netherlands) during the period of 1980–1998 and the Euro/US$ exchange rate was used from 1999 onwards.

Short–term Interest Rate: The data (measured in percent per annum) were taken from IFS Series 60B..ZF (money market – interbank – rate) for 16 countries. The data for Argentina, Chile, China and Turkey were taken from IFS Series 60L..ZF (deposit rate). For Sweden, IFS

Series 60B..ZF was completed by IFS Series 60A..ZF from 2004Q4. For Mexico, IFS Series 60C..ZF (Treasury bill rate) was used while IFS Series 60..ZF (discount rate) were used for New Zealand and Peru. For India, the data covering the period of 1998Q2–2006Q2 were retrieved from the Reserve Bank of India. No reliable short–term interest rate is published by the Saudi Arabian Monetary Agency. For Norway, the NIBOR 3–month rates from the OECD was used. For the Eurozone countries, Finland, Germany, Italy and Spain had their own short–term interest rate series over the full sample period while the series for the 4 remaining countries (Austria, Belgium, France, and Netherlands) ended at 1998Q4. For these latter countries, their interest rate series were completed by the Euro interbank rate.

Exports and Imports: The data for exports and imports (measured in millions US$) of 33 countries were from IFS Series 70..DZF (for exports) and IFS Series 71..DZF (for imports). Where necessary , the data were extrapolated backward using and export and import growth rates obtained from the World Bank data. This technique was applied for China's export and import in 1980 and for Belgium's export and import over 1980–1992. The quarterly series for Saudi Arabia were interpolated from the annual series. All the series were seasonally adjusted using the US Census Bureau's X12 routine.

Equity Price Index: The data were collected from IFS Series 62..ZF (industrial share prices index) for 26 countries. The IFS series of Argentina, Singapore and Thailand were completed using data from Datastream. The data for the UK, Switzerland and Mexico were collected from the OECD's Main Economic Indicators. Reliable equity price index data for China, Indonesia, Peru, Turkey and Saudi Arabia were unavailable.

Oil Price: The UK Brent series (US$ per barrel) from IFS Commodity Price was used.

References

Adolfson, M., Lindé, J. and Villani, M. (2007) "Forecasting Performance of an Open Economy DSGE Model," *Econometric Reviews*, 26(2), 289-328. 1

Bank of England (2008) "Inflation Report: February 2008," London: Bank of England.

Barro, R.J. and Sala-i-Martin, X. (1997) "Technological Diffusion, Convergence, and Growth," *Journal of Economic Growth*, 2, 1-26.

Bayoumi, T. (2004) "GEM: A New International Macroeconomic Model," Occasional Paper No. 239, Washington D.C.: International Monetary Fund. 2

Botman, D., Karam, P., Laxton, D. and Rose, D. (2007) "DSGE Modeling at the Fund: Applications and Further Developments," Working Paper No. 07/200, Washington D.C.: International Moneon block-diagonal covarianctary Fund. 2

Bussière, M., Chudik, A. and Sestieri, G. (2009) "Modelling Global Trade Flows: Results from a GVAR model," Working Paper No. 1087, Frankfurt: European Central Bank. 1

Casillas-Olvera, G. and Bessler, D. (2006) "Probability Forecasting and Central Bank Accountability," *Journal of Policy Modeling*, 28(2), 223-234.

Chen, Q., Gray, D., N'Diaye, P., Oura, H. and Tamirisa, N. (2009) "International Transmission of Bank and Corporate Distress," Working Paper No. WP/10/124, Washington D.C.: International Monetary Fund. 1

Cristadoro, R., Gerali, A., Neri, S. and Pisani, M. (2006) "Nominal Rigidities in an Estimated Two Country DSGE Model." Paper presented at the 12^{th} International Conference on Computing in Economics and Finance, Limassol (Cyprus), June 22-24, 2006. 2

Dees, S., di Mauro, F., Pesaran, M.H. and Smith, L.V. (2007) "Exploring the International Linkages of the Euro Area: A Global VAR Analysis," *Journal of Applied Econometrics*, 22, 1-38. 1

Dees, S. Holly, S., Pesaran, M.H. and Smith, L.V. (2007) "Long Run Macroeconomic Relations in the Global Economy," *Economics*, 3, 1-56. 1

Del Negro, M. and Schorfheide, F. (2004) "Priors from General Equilibrium Models for VARs," *International Economic Review*, 45(2), 643-3. 2

de Walque, G., Smets, F. and Wouters, R. (2005) "An Estimated Two-Country DSGE Model for the Euro Area and the US Economy," Paper presented at the 21^{st} Annual European Meeting of the Econometric Society, Vienna, August 27, 2006. 2

Diebold, F.X. and Yilmaz, K. (2009) "Measuring Financial Asset Return and Volatility Spillovers, with Application to Global Equity Markets," *Economic Journal*, 119, 158-171. 2.4

Diebold, F.X. and Yilmaz, K. (2011) "On the Network Topology of Variance Decompositions: Measuring the Connectedness of Financial Firms," Working Paper No. 17490, Cambridge (MA): National Bureau of Economic Research. 2.4

Dornbusch, R. (1976) "Expectations and Exchange Rate Dynamics," *Journal of Political Economy*, 84, 1161-1176. 4.5

Ericsson, N.R. (2001) "Forecast Uncertainty in Economic Modeling," International Finance Discussion Paper No. 697, Washington D.C.: Board of Governors of the Federal Reserve System.

Garratt, A., Lee, K, Pesaran, M.H. and Shin, Y. (2006) *Global and National Macroeconometric Modelling: A Long-Run Structural Approach*. Oxford: Oxford University Press.

Giordani, P. and Söderlind, P. (2003) "Inflation Forecast Uncertainty," *European Economic Review*, 47(6), 1037-1059.

Greenspan, A. (1996) "The Challenge of Central Banking in a Democratic Society." Remarks at the Annual Dinner and Francis Boyer Lecture of the American Enterprise Institute for Public Policy Research, Washington D.C., December 5, 1996.

Greenwood-Nimmo, M.J., Nguyen, V.H. and Shin, Y. (2012a) "Probabilistic Forecasting of Output Growth, Inflation and the Balance of Trade in a GVAR Framework," *Journal of Applied Econometrics*, 27(4), 554-573. (document), 1

Greenwood-Nimmo, M.J., Nguyen, V.H. and Shin, Y. (2012b) Using Global VAR Models for Scenario-Based Forecasting and Policy Analysis. In F. di Mauro and M.H. Pesaran (Eds.) "*The GVAR Handbook: Structure and Applications of a Macro Model of the Global Economy for Policy Analysis*," (Chapter 7). Oxford: OUP. Forthcoming. 1

Officer, L.H. (1976) "The Productivity Bias in Purchasing Power Parity: An Econometric Investigation," *IMF Staff Papers*, 23, 545-579.

Pagan, A. (2003) "Report on Modelling and Forecasting at the Bank of England," *Bank of England Quarterly Bulletin*, 43(1), 1-29. 2

Pesaran, M.H., Schuermann, T. and Smith, L.V. (2009) "Forecasting Economic and Financial Variables with Global VARs," *International Journal of Forecasting*, 25(4), 642-675.

Pesaran, M.H., Schuermann, T. and Weiner, S.M. (2004) "Modeling Regional Interdependencies Using a Global Error-Correcting Macroeconometric Model," *Journal of Business and Economic Statistics*, 22, 129-162. 1

Pesaran, M.H. and Shin, Y. (2002) "Long-Run Structural Modelling," *Econometric Reviews*, 21, 49-87. 2.1

Pesaran, M.H., Shin Y. and Smith, R.J. (2000) "Structural Analysis of Vector Error Correction Models with Exogenous I(1) Variables," *Journal of Econometrics*, 97, 293-343.

Sgherri, S. and Galesi, A. (2009) "Regional Financial Spillovers Across Europe: A Global VAR Analysis," Working Paper No. 09/23, Washington D.C.: International Monetary Fund. 1

Shin, Y. (2009) "The Cointegrating VAR Modelling Approach to the Korean Macroeconomy in the Presence of Structural Breaks," *The Korean Journal of Economics*, 16: 175-241. 1, 2.1, 4, 4.1, 4.2, 4.5

Sims, C. (1980) "Macroeconomics and Reality," *Econometrica*, 48, 1-48. 2

Smets, F. and Wouters, R. (2007) "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," *American Economic Review*, 97(3), 586-606. 1

Order	Country	Code	r	n	k	Official Inflation Target	Probable Cause of Break
0	USA	USA	3	7	3	None	
1	Eurozone*	EUR	3	7	5	HICP $<2\%$ & $\approx 2\%$	Introduction of the Euro (1999Q1)
2	Japan	JAP	6	7	5	None	The real-estate/stock market crash (1992Q1)
3	UK	UK	3	7	5	2% CPI $\pm 1\%$	Departure from the ERM (1992Q4)
4	Norway	NOR	3	7	5	2.5% CPI	
5	Sweden	SWE	4	7	5	2% CPI $\pm 1\%$	
6	Switzerland	SWI	5	7	5	$<2\%$ CPI	
7	Canada	CAN	3	7	5	2% CPI $\pm 1\%$	
8	Australia	AUS	3	7	5	2-3% CPI	
9	New Zealand	NZ	3	7	5	1-3% CPI	
10	South Africa	SAF	3	7	5	3-6% CPIX	
11	Argentina	ARG	5	7	5	None	Effects of the Convertibility Plan (1991Q4)
12	Brazil	BRA	3	7	5	4.5% CPI $\pm$ 2%	Effects of the Real Plan (1994Q4)
13	Chile	CHL	4	7	5	3% CPI $\pm 1\%$	
14	Mexico	MEX	4	7	5	3% CPI	Mexican Peso Crisis (1995Q2)
15	India	IND	3	7	5	None	
16	Korea	KOR	4	7	5	3% CPI $\pm$ of 0.5%	S.E. Asian crisis (1997Q4)
17	Malaysia	MAL	5	7	5	None	S.E. Asian crisis (1997Q3)
18	Philippines	PHI	3	7	5	4-5% CPI	S.E. Asian crisis (1997Q4)
19	Singapore	SNG	4	7	5	None	
20	Thailand	THA	4	7	5	0-3.5% CPIX	S.E. Asian crisis (1997Q3)
21	China	CHN	3	6	5	None	
22	Indonesia	INS	4	6	5	5% CPI $\pm$ 1%	S.E. Asian crisis (1997Q3)
23	Peru	PER	4	6	5	1-3% CPI	Dollarisation 'Washington consensus' (1994Q3)
24	Turkey	TUR	2	6	5	5% CPI	
25	Saudi Arabia	SAR	4	5	5	None	

Note: r , n and k are the numbers of cointegrating vectors, endogenous variables and exogenous variables for each country/region, respectively. (.) is our chosen break point. * For our purposes, the Eurozone includes Austria, Belgium, Finland, France, Germany, Italy, the Netherlands and Spain only. Eurozone data are constructed by aggregating the contributions of these member states using a PPP-GDP weighting scheme. The only exceptions are Eurozone's export and import series which are the total of member states exports and imports, respectively.

Table 1: Details of Country-Specific Models in the GVAR Framework

	Inflation				Output Growth			
	Mean	St. dev.	Max	Min	Mean	St. dev.	Max	Min
US	3.45	2.28	11.3	-3.42	3.05	2.68	8.92	-6.61
EU	3.41	2.36	11.8	0.02	2.17	2.25	14.3	-2.84
JAP	0.99	2.53	9.42	-4.0	2.58	3.75	12.4	-7.51
UK	4.18	3.66	19.2	-2.68	2.57	2.25	8.81	-4.64
NOR	4.05	3.93	18.5	-6.70	2.85	7.24	26.8	-12.9
SWE	4.01	4.29	18.6	-3.82	2.41	4.53	15.0	-8.51
SWI	2.20	2.65	9.56	-2.61	1.71	2.16	7.61	-2.87
CAN	3.51	3.14	12.8	-3.67	2.76	3.01	9.87	-6.08
AUS	4.48	3.68	16.3	-1.67	3.26	3.17	11.6	-6.09
NZ	5.08	5.65	34.2	-3.18	3.21	8.68	41.3	-31.8
SAF	9.41	5.56	22.9	-8.33	2.29	3.39	10.0	-8.55
ARG	70.2	118.8	759.2	-4.20	1.95	9.23	21.3	-25.4
BRA	97.4	120.8	622.6	-1.41	2.55	7.00	19.2	-29.0
CHL	11.0	9.80	46.2	-1.42	4.49	8.31	33.2	-25.8
MEX	26.1	26.7	131.4	-0.43	2.64	6.26	15.1	-24.7
IND	7.54	6.76	24.2	-16.0	5.97	6.09	28.4	-12.9
KOR	4.95	4.92	28.7	-2.72	6.43	6.80	26.2	-34.3
MAL	3.02	2.78	14.9	-2.43	5.95	6.14	19.9	-26.8
PHI	8.94	10.1	63.6	-14.0	2.99	6.08	18.0	-25.0
SIN	1.67	2.64	13.7	-4.63	6.76	6.42	26.9	-13.8
THA	3.89	3.59	15.8	-4.98	5.69	6.28	25.2	-20.5
CHN	5.37	7.08	33.9	-2.87	9.48	3.16	17.3	0.69
INDO	10.03	12.0	73.1	-9.08	4.68	9.46	48.6	-37.3
PER	66.93	121.8	856.53	-2.38	2.39	12.9	28.0	-55.0
TUR	40.10	22.6	136.1	3.07	4.41	9.98	25.6	-46.2
SAU	0.51	3.57	17.6	-18.4	1.66	9.01	20.1	-23.0

Table 2: Historical Inflation and Output Growth by Country/Region (% per annum)

	Import Growth				Export Growth				Current
	Mean	St. dev.	Max	Min	Mean	St. dev.	Max	Min	Account
US	4.11	12.2	50.1	-36.2	2.62	11.6	27.6	-29.3	-1.49
EU	2.88	12.2	31.8	-25.8	3.38	11.3	33.2	-20.7	0.50
JAP	1.88	21.0	48.1	-60.9	2.86	15.6	40.2	-49.9	0.98
UK	2.39	16.2	65.9	-49.4	1.30	18.6	38.1	-86.8	-1.09
NOR	2.22	21.0	53.7	-44.7	3.89	25.8	59.8	-93.7	1.66
SWE	3.21	16.4	46.0	-57.9	4.26	17.3	66.40	-35.5	1.05
SWI	1.82	16.2	80.2	-36.7	2.79	13.5	34.50	-30.7	0.96
CAN	3.00	18.1	64.8	-50.1	3.20	18.3	99.3	-48.6	0.20
AUS	4.17	17.1	38.9	-72.5	3.49	20.8	80.8	-50.7	-0.68
NZ	2.37	28.6	82.5	-80.2	1.56	20.8	55.5	-52.6	-0.80
SAF	4.26	32.5	83.5	-106.4	2.64	29.7	61.3	-85.2	-1.62
ARG	5.51	61.6	338.2	-178.5	7.44	69.4	391.4	-166.6	1.93
BRA	2.38	37.6	103.7	-85.4	4.27	49.6	191.2	-174.5	1.89
CHL	6.01	27.6	57.4	-92.1	8.58	31.8	114.1	-93.1	2.57
MEX	6.63	30.0	119.8	-175.9	6.84	44.5	229.1	-139.6	0.20
IND	8.56	30.2	88.4	-127.6	9.02	23.9	78.8	-58.9	0.46
KOR	6.97	22.5	87.3	-65.5	8.18	27.2	120.9	-67.9	1.20
MAL	8.34	22.3	63.2	-65.1	8.04	21.0	71.1	-64.1	-0.30
PHI	4.92	34.3	76.7	-137.7	5.85	51.4	305.3	-150.7	0.93
SIN	5.87	17.5	40.5	-41.4	7.13	17.8	65.6	-34.6	1.26
THA	8.23	25.7	79.6	-92.8	10.0	24.0	87.2	-92.8	1.78
CHN	14.0	35.4	149.7	-139.9	16.1	24.9	119.0	-43.1	2.11
INDO	8.05	53.4	163.8	-226.5	5.70	52.5	255.4	-258.0	-2.35
PER	1.14	46.3	137.1	-168.9	0.63	52.4	218.3	-153.7	-0.51
TUR	7.78	34.5	137.9	-78.2	9.70	38.9	129.1	-119.4	1.91
SAU	3.88	18.9	35.7	-47.3	2.96	36.0	83.8	-67.1	-0.93

Table 3: Historical Imports and Exports Growth and Current Account Position by Country/Region (% per annum)

Horizon	re	r	im	ex	q	π	y
$h=1$	KOR re (22%)	KOR r (67%)	KOR im (62%)	KOR ex (59%)	KOR q (58%)	KOR im (5%)	KOR y (68%)
	JAP re (14%)	US y (4%)	KOR ex (12%)	KOR re (13%)	US q (16%)	KOR dp (61%)	KOR im (9%)
	EU re (10%)	BRA r (3%)	KOR y (9%)	KOR im (12%)	po (6%)	US q (8%)	US q (7%)
$h=4$	EU re (20%)	KOR r (20%)	KOR im (28%)	KOR re (14%)	KOR q (31%)	KOR im (21%)	po (28%)
	KOR re (16%)	KOR re (19%)	US q (15%)	KOR ex (16%)	po (21%)	KOR dp (17%)	KOR y (26%)
	KOR q (15%)	KOR q (12%)	KOR dp (9%)	US q (13%)	US q (13%)	US q (12%)	US p (11%)
$h=8$	EU re (21%)	KOR re (20%)	KOR im (24%)	po (19%)	po (30%)	KOR im (23%)	po (39%)
	KOR q (15%)	KOR q (19%)	US q (21%)	US q (13%)	KOR q (23%)	KOR dp (17%)	KOR y (15%)
	KOR re (12%)	US q (13%)	KOR dp (10%)	US p (10%)	US p (12%)	US q (16%)	US p (11%)
$h=12$	EU re (20%)	KOR re (20%)	KOR im (24%)	po (18%)	po (34%)	KOR im (25%)	po (43%)
	KOR q (14%)	KOR q (20%)	US q (19%)	KOR re (8%)	KOR q (21%)	KOR dp (16%)	KOR y (13%)
	KOR re (11%)	US q (14%)	KOR dp (10%)	US q (8%)	US p (11%)	US q (16%)	US p (10%)
Average	EU re (20%)	KOR r (20%)	KOR im (29%)	KOR ex (14%)	KOR q (30%)	KOR im (21%)	po (32%)
	KOR re (15%)	KOR re (17%)	US q (16%)	po (13%)	po (25%)	KOR dp (20%)	KOR y (24%)
	KOR q (13%)	KOR q (14%)	KOR dp (9%)	KOR re (13%)	US q (12%)	US q (14%)	US p (10%)

Table 4: Main Contributors to GFEVDs of Korean Variables

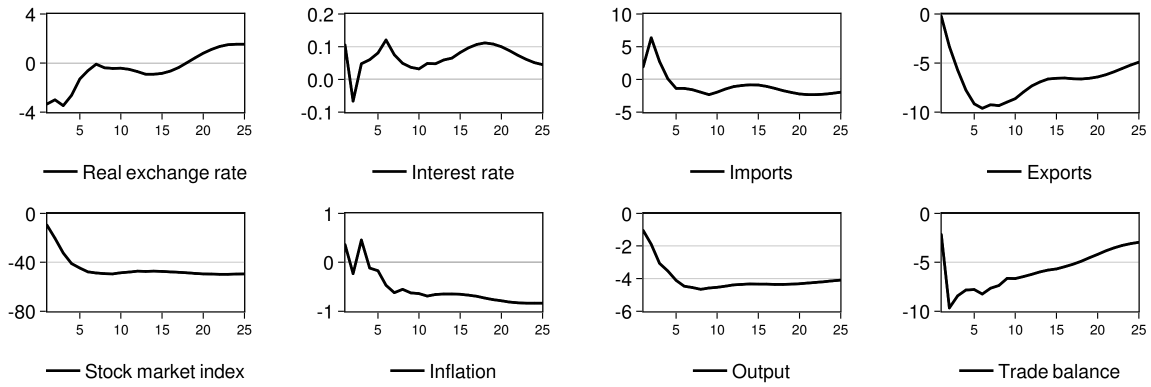


Figure 1: GIRFs w.r.t. a Positive Oil Price Shock

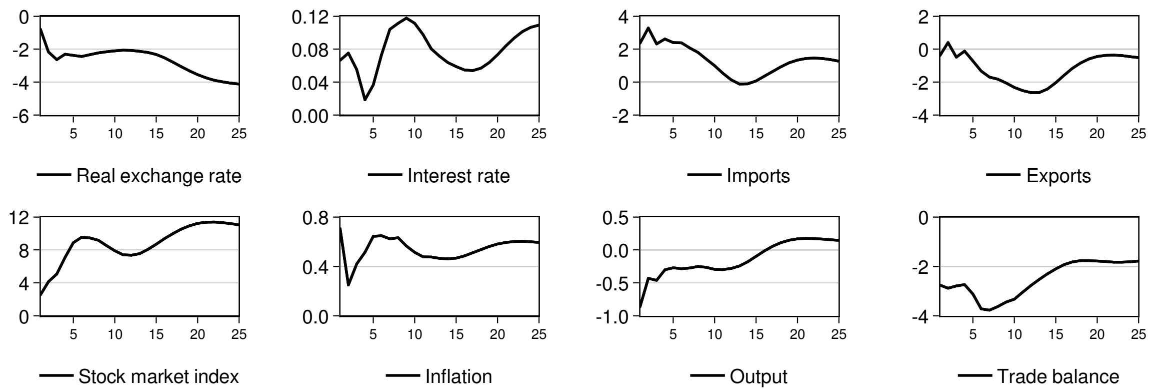


Figure 2: GIRFs w.r.t. a Positive US Interest Rate Shock

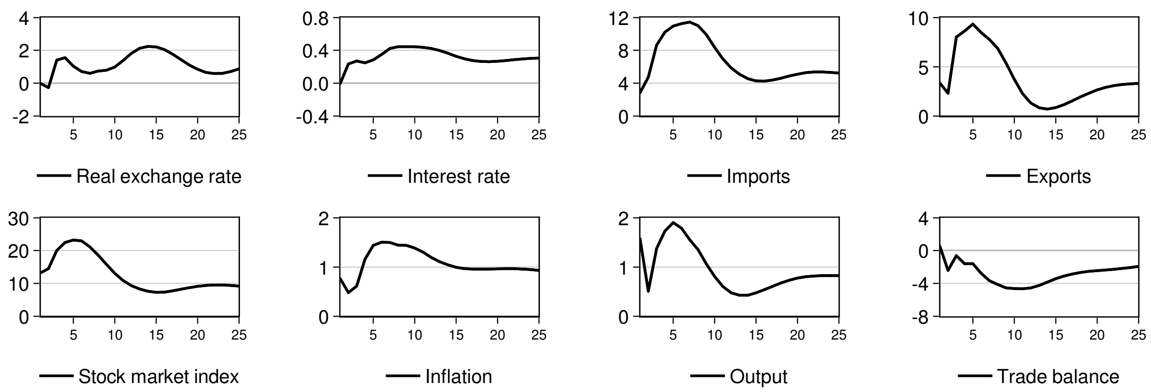


Figure 3: GIRFs w.r.t. a Positive US Stock Market Shock

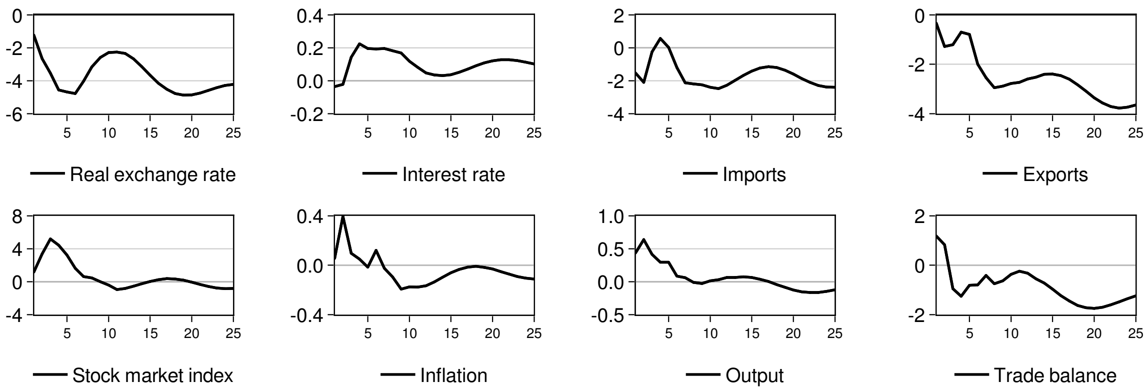


Figure 4: GIRFs w.r.t. a Positive Chinese Inflation Shock

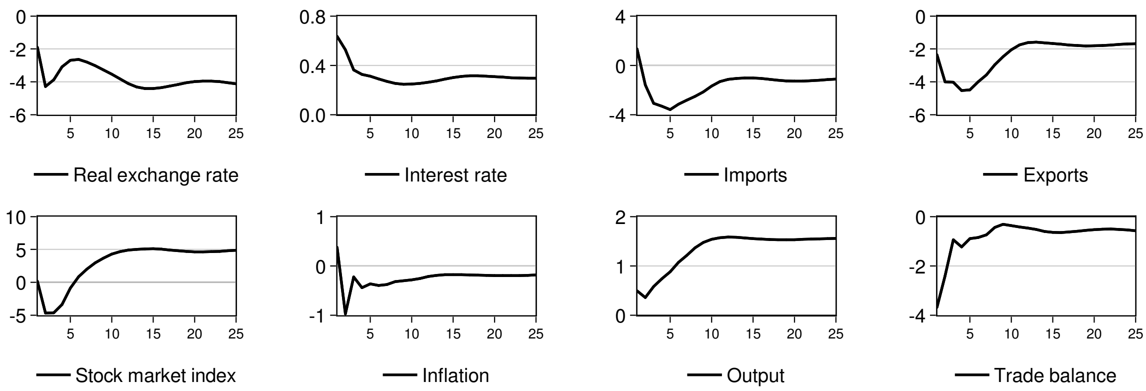
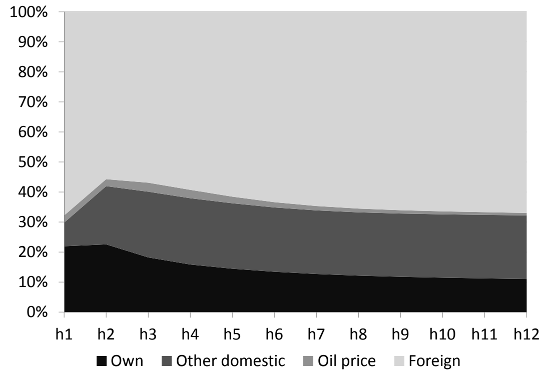
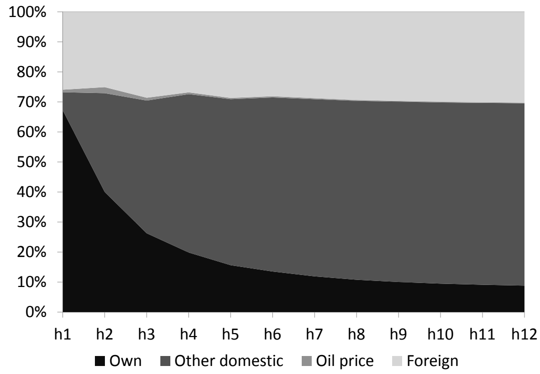


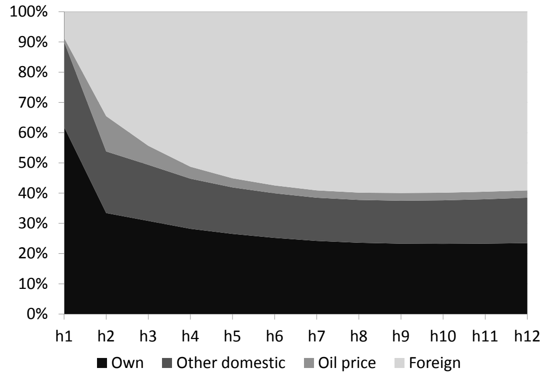
Figure 5: GIRFs w.r.t. a Positive Korean Interest Rate Shock



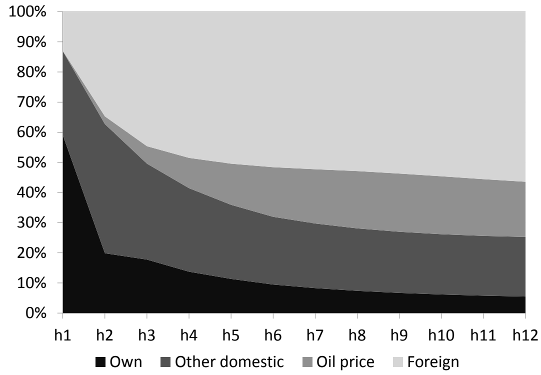
(a) Real exchange rate



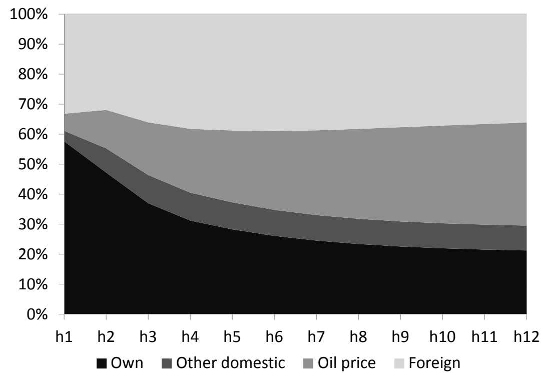
(b) Interest rate



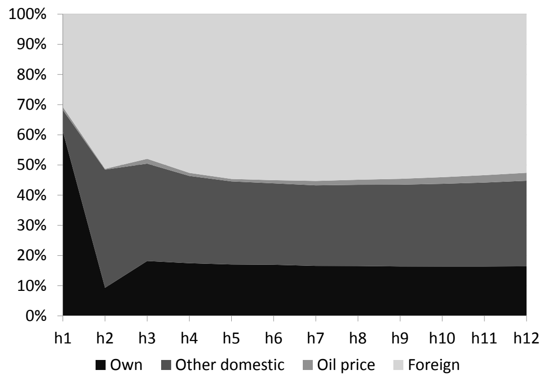
(c) Imports



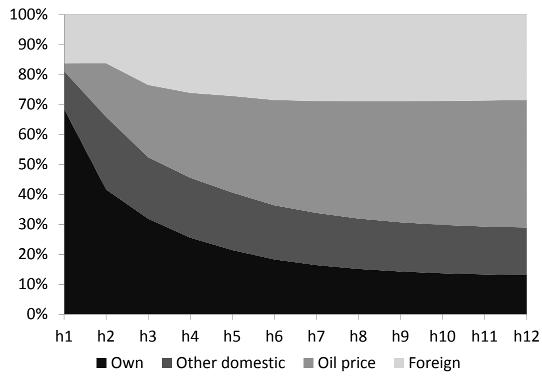
(d) Exports



(e) Stock market index



(f) Inflation



(g) Output

Figure 6: GFEVDs of Korean variable at $h = 1, ..., 12$.

1 Introduction

Traditional approaches to macroeconometric modelling are typically focused on the national level, albeit sometimes with the inclusion of one or more satellite models representing important trading partners or the rest of the world economies. A good example of such a country-specific model in the case of Korea is Shin (2009). The principle limitation to the development of larger scale multi-country and global models has been the curse of dimensionality. Indeed, the construction of a pth order cointegrating VAR model in m core variables for each of $N+1$ separate economies would necessitate the estimation of $mp(N+1)$ parameters. The dimensionality of such a model clearly increases proportionately with m, N and p, rendering it an infeasible approach for the analysis of anything but relatively simple and naïve systems given the range and frequency of most existing macroeconomic datasets.

The global vector autoregressive (GVAR) framework developed in a sequence of papers by Pesaran, Schuermann and Weiner (2004, PSW), Dees, di Mauro, Pesaran and Smith (2007, DdPS) and Dees, Holly, Pesaran and Smith (2007, DHPS) offers a new approach to large scale macroeconometric modelling that circumvents this issue. The main innovation of GVAR is the exploitation of an underlying linking scheme by which $N+1$ country-specific VARX models are combined into a coherent global system. This is achieved by the inclusion of weakly exogenous foreign variables within each country-specific model. These foreign variables are defined as weighted averages of the variables in the remaining N countries in the global system (*i.e.* the foreign variables for country i are defined as appropriately weighted averages of the corresponding variables for all countries $j \neq i$). It is the use of mutually consistent bilateral weights that provides the desired linkages required to construct the global system.

By virtue of their ability to explicitly model national, regional and global linkages, GVAR models represent a powerful tool for the analysis of global phenomena, including business cycle linkages (*e.g.* DdPS; DHPS), financial contagion (*e.g.* PSW; Chen et al., 2009; Sgherri and Galesi, 2009) and global imbalances (*e.g.* Bussière et al., 2009; Greenwood-Nimmo, Nguyen and Shin, 2012a, GNS; Greenwood-Nimmo, Nguyen and Shin, 2012b). This paper employs the GVAR model developed by GNS to investigate the international linkages of the South Korean economy. The GNS model is estimated for the same group of 33 countries (26 regions) considered by DdPS and DHPS over the extended sample period 1980Q2-2007Q2. However, unlike these papers, the GNS model includes real exports and imports in order to facilitate the analysis of global trade imbalances. Furthermore, the country-specific models embedded within the GNS framework are based upon the CVARX model of Shin (2009) in the sense that they allow for one-time permanent intercept shifts in selected countries that have suffered acute and disruptive events during the sample period. In particular, the GNS model accounts for the 1997 Asian banking crisis, the introduction of the Euro, the Japanese real estate collapse, the Black Wednesday event in the UK and the various South American hyperinflationary episodes.

The original application of the GNS model was to the probabilistic forecasting of scenarios relating to inflation, output growth and the balance of trade in a focus group of four countries (the USA, the Eurozone, Japan and China). Subsequently, the model has been applied to the counterfactual analysis of policy-relevant scenarios in the same group of focus countries by exploiting linear combinations of generalised impulse response functions, or GIRFs (Greenwood-Nimmo, Nguyen and Shin, 2012b). In this paper, our focus is upon more extended impulse response analysis and forecast error variance decomposition (FEVD) as tools with which to assess the bidirectional connections or linkages between Korea and the global economy.

Our results provide a number of interesting insights. Firstly, impulse response analysis reveals that the real side of the Korean macroeconomy is highly sensitive to the price of crude oil while the nominal side exhibits a relatively muted response, presumably reflecting the interventionist energy policies enacted in the earlier years of our sample. Next, one important, if unsurprising, finding is that both the financial and real sides of the Korean economy respond rapidly and strongly to the US stock market, reflecting Korea's integration into the global financial community. Importantly, we also find that the prospects of the Korean economy are not only intimately linked with those of the US but also of China. Such strong external influences will significantly complicate the task of domestic macroeconomic management faced by the Korean monetary and fiscal authorities.

In a step beyond the widespread practice in the GVAR literature, we analyse the h step ahead FEVDs of a given Korean domestic variable in terms of its own contribution to the variance share, the contribution of the remaining domestic variables, the contribution of the oil price and the contribution of the remaining foreign variables in the global system. In this way, we find that with the exception of the interest rate, the remaining Korean variables respond strongly to conditions overseas. At an over-arching level, our analysis reveals that the prospects of the Korean economy are closely linked to the core macroeconomic performance of the US economy, the performance of the American, European and Japanese stock markets and the performance of the Chinese economy, especially in terms of inflation. To reiterate a point from above, these close international linkages will inevitably complicate the task of economic management and stabilisation.

This paper proceeds in 6 sections. Section 2 introduces the GNS GVAR model and discusses the framework for dynamic analysis, while Section 3 provides some preliminary analysis of the dataset used, draws out some stylised facts and summarises a range of pre-testing exercises conducted in GNS. Section 4 evaluates the impact of a range of shocks on the Korean economy by means of impulse response analysis, while Section 5 identifies key global variables relevant for Korea using forecast error variance decompositions. Section 6 concludes. Detailed notes on the dataset are contained in an Appendix.

2 The GNS GVAR Model

The need for sophisticated multi-country and global models has become increasingly apparent with the deepening and widening of both regional and global linkages associated with the continuing process of globalisation. However, the development and estimation of global macroeconometric models has generally proven infeasible due to the curse of dimensionality. Much of the existing research into two-country and multi-country modelling has therefore employed calibrated DSGE models. Notable examples include de Walque et al. (2005), Cristadoro et al. (2006) and the IMF's Global Economy Model (GEM) and Global Fiscal Model (GFM), which are neatly summarised by Bayoumi (2004) and Botman et al. (2007). Nevertheless, large scale multi-country DSGE models remain relative rare due to the complexity of the modelling that is required to deliver the rich microfoundations that are considered the principle advantage of DSGE models relative to more data-driven approaches such as VAR.

The GVAR Error-Correcting framework represents an alternative and complementary approach to the so-called new open economy macroeconomics (NOEM) paradigm. The contrast between the ease of estimation and empirical strength of VAR and the benefits of the theoretical microfoundations of DSGE models has been well documented (Pagan, 2003). The construction of a DSGE model where the number of countries exceeds two or three is highly computationally demanding and it is here that GVAR enjoys a distinct advantage. The principle of parsimony suggests that the relatively more simple but flexible GVAR specification should be preferred to the DSGE model in terms of out-of-sample forecasting if it can provide a similar degree of accuracy.[1] Moreover, one may prefer a comparatively unrestricted GVAR model to a DSGE model with its inherent reliance on deep parameters and behavioural assumptions, particularly if one follows the logic of Sims (1980) in terms of letting the data 'speak for itself'.[2]

The remainder of this section provides a detailed derivation of the GNS GVAR model. As will become clear, the principle innovation of GVAR relative to more traditional approaches to large-scale macroeconometric modelling is the construction of country-specific CVARX* models that include weakly exogenous foreign variables. These foreign variables are computed as weighted averages of the corresponding variables for each of the remaining countries in the global system (*i.e.* in a three country system, country 1's foreign GDP series would be a weighted average of the GDP of countries 2 and 3). This approach introduces fundamental linkages between the country-specific CVARX* models which may be exploited by means of carefully constructed link matrices, thereby allowing one to combine the country-specific models into a global system. In this way, GVAR models may be constructed for large global systems, the dimensionality of which would preclude their estimation using traditional techniques.

2.1 National Modelling

Shin (2009) develops a small quarterly macroeconometric model for Korea following the long-run structural modelling approach of GLPS. The model is estimated over the period 1982q3–2006q2 in six endogenous domestic variables and three weakly exogenous foreign variables. Among the domestic variables are the bilateral nominal KRW/USD exchange rate, the nominal 90 day money market rate, the rate of consumer price inflation, real per capita GDP, producer prices relative to the OECD countries and the ratio of real per capita M1 to real GDP. Similarly, the foreign variables include the price of crude oil, the US nominal 90 day Treasury Bill rate and real per capita GDP for the OECD economies. Importantly, Shin extends the long-run structural modelling approach associated with Pesaran and Shin (2002) by incorporating a common one-time permanent intercept shift at 1997q4 in the CVARX* model. Shin argues that the inclusion of break dummies is important in this case as it accounts for the repercussions of the 1997 East Asian banking crisis on the Korean macroeconomy in the short-run as well as in relation to its governing long-run economic relations.

[1] It must be noted, however, that recent advances in Bayesian DSGE modelling have significantly narrowed the gap in forecasting performance (*c.f.* Smets and Wouters, 2007, and Adolfson et al., 2007).

[2] A number of interesting intermediate cases obtain between the extremes of unrestricted VAR and DSGE, including over-identified cointegrating VAR and DSGE-VAR (*c.f.* Del Negro and Schorfheide, 2004).

The GVAR model developed by GNS continues in this vein by incorporating country-specific structural breaks within the global framework. The same 26 countries/regions studied by DdPS are included, as summarised in Table 1 which reproduces part of Table 1 from GNS. It also records the timing and probable cause of the structural breaks included in the country-specific and global models. GNS argue that explicit inclusion of structural breaks will improve the accuracy of their estimation and forecasting results, especially for the East Asian economies (including Korea) and for the South American countries that recorded hyperinflationary episodes in the 1980s. Further breaks are included to account for the introduction of the Euro, the Japanese real-estate collapse and the Black Wednesday event in the UK.

[Insert Table 1 about here]

Two key differences between Shin's model and the country-specific model for Korea embedded within the GNS GVAR model are: (i) the selection of endogenous and exogenous variables in each case; in particular, the scope of the GNS model is broader, including the domestic and foreign equity prices and the trade variables (real exports and imports), though the monetary aggregate variables cannot be accommodated in the global model mainly due to difficulties in collecting those homogenous aggregates across countries in a consistent way; and (ii) the more general construction of the weakly exogenous foreign variables as trade-weighted averages in GNS but simply as the relevant US or OECD variables in Shin. We would therefore expect each model to have different strengths.

Adopting the notation used in GNS, the model comprises $N+1$ economies indexed by $i = 0, 1, .., N$. For each country-specific model, the set of domestic variables are denoted by an $m_i \times 1$ vector, $\boldsymbol{x}_{it}$ and the associated country-specific foreign variables by an $m_i^* \times 1$ vector $\boldsymbol{x}_{it}^*$ defined as $\boldsymbol{x}_{it}^* = \sum_{j=0}^{N} w_{ij}\boldsymbol{x}_{jt}$, where $w_{ij} \geq 0$ are the weights attached to the foreign variables with $\sum_{j=0}^{N} w_{ij} = 1$, and $w_{ii} = 0$ for all i. PSW show that the definition of the weakly exogenous foreign variables for country i as weighted averages of variables for countries, $j \neq i$, results in a simultaneous system of equations that may be solved to form a global system. The exploitation of these linkages represents the key innovation of the Global VAR framework.

Following Shin, GNS write the second order country-specific VARX* $(2,2)$ model as

$$\begin{aligned} \boldsymbol{x}_{it} &= \boldsymbol{h}_{i0} + \boldsymbol{h}_{i1}t + \boldsymbol{\delta}_{i0}d_{it} + \boldsymbol{\delta}_{i1}d_{i,t-1} + \boldsymbol{\delta}_{i2}d_{i,t-2} + \boldsymbol{\Phi}_{i1}\boldsymbol{x}_{i,t-1} \\ &+ \boldsymbol{\Phi}_{i2}\boldsymbol{x}_{i,t-2} + \boldsymbol{\Psi}_{i0}\boldsymbol{x}_{it}^* + \boldsymbol{\Psi}_{i1}\boldsymbol{x}_{i,t-1}^* + \boldsymbol{\Psi}_{i2}\boldsymbol{x}_{i,t-2}^* + \boldsymbol{u}_{it}, \end{aligned} \quad (1)$$

where d_{it} is the country-specific intercept shift variable and $\boldsymbol{u}_{it} \sim iid\,(0, \boldsymbol{\Sigma}_{ii})$, where $\boldsymbol{\Sigma}_{ii}$ is an $m_i \times m_i$ positive definite variance-covariance matrix. The coefficient vectors $\boldsymbol{h}_{ij}$, $j = 0, 1$ and $\boldsymbol{\delta}_{ij}$, $j = 0, 1, 2$, are of dimension $m_i \times 1$, while $\boldsymbol{\Phi}_{ij}$, $j = 1, 2$, and $\boldsymbol{\Psi}_{ij}$, $j = 0, 1, 2$, are $m_i \times m_i$ and $m_i \times m_i^*$ matrices, respectively.

The country-specific CVARX* models are estimated allowing for unit roots and cointegration using the Johansen eigenvalue routine under the assumption that the country-specific foreign variables are weakly exogenous. Hence, the VECM form of (1) may be written as

$$\begin{aligned}\Delta \boldsymbol{x}_{it} &= \boldsymbol{c}_{i0} + \boldsymbol{c}_{i0}^* \Delta d_{it} + \boldsymbol{c}_{i1}^* \Delta d_{i,t-1} + \boldsymbol{\Lambda}_i \Delta \boldsymbol{x}_{it}^* + \boldsymbol{\Gamma}_i \Delta \boldsymbol{z}_{i,t-1} \\ &+ \boldsymbol{\alpha}_i \boldsymbol{\beta}_i' \left(\boldsymbol{z}_{i,t-1} - \boldsymbol{\mu}_i d_{i,t-1} - \boldsymbol{\gamma}_i (t-1) \right) + \boldsymbol{u}_{it}, \end{aligned} \tag{2}$$

where $\boldsymbol{z}_{it} = (\boldsymbol{x}_{it}', \boldsymbol{x}_{it}^{*\prime})'$, $\boldsymbol{\alpha}_i$ is the $m_i \times r_i$ country-specific matrix of adjustment coefficients of rank r_i and $\boldsymbol{\beta}_i$ is the $(m_i + m_i^*) \times r_i$ long-run matrix of rank r_i. Noting that $\boldsymbol{\beta}_i' (\boldsymbol{z}_{it} - \boldsymbol{\mu} d_{it} - \boldsymbol{\gamma}_i t)$ can be decomposed into $\boldsymbol{\beta}_{ix}' \boldsymbol{x}_{it} + \boldsymbol{\beta}_{ix^*}' \boldsymbol{x}_{it}^* - \left(\boldsymbol{\beta}_i' \boldsymbol{\mu}_i\right) d_t - \left(\boldsymbol{\beta}_i' \boldsymbol{\gamma}_i\right) t$, it is straightforward to test the co-trending restrictions, $\boldsymbol{\beta}_i' \boldsymbol{\gamma}_i = 0$, and the co-breaking restrictions, $\boldsymbol{\beta}_i' \boldsymbol{\mu}_i = 0$.

It follows that (1) can be written more compactly as

$$\boldsymbol{A}_{i0} \boldsymbol{z}_{it} = \boldsymbol{h}_{i0}^* + \boldsymbol{h}_{i1} t + \boldsymbol{A}_{i1} \boldsymbol{z}_{i,t-1} + \boldsymbol{A}_{i2} \boldsymbol{z}_{i,t-2} + \boldsymbol{u}_{it}, \tag{3}$$

where

$$\underset{m_i \times (m_i + m_i^*)}{\boldsymbol{A}_{i0}} = (\boldsymbol{I}_{m_i}, -\boldsymbol{\Psi}_{i0})\,; \quad \underset{m_i \times (m_i + m_i^*)}{\boldsymbol{A}_{i1}} = (\boldsymbol{\Phi}_{i1}, \boldsymbol{\Psi}_{i1})\,; \quad \underset{m_i \times (m_i + m_i^*)}{\boldsymbol{A}_{i2}} = (\boldsymbol{\Phi}_{i2}, \boldsymbol{\Psi}_{i1})\,;$$

$$\boldsymbol{h}_{i0}^* = \boldsymbol{h}_{i0} + \boldsymbol{\delta}_{i0} d_{it} + \boldsymbol{\delta}_{i1} d_{i,t-1} + \boldsymbol{\delta}_{i2} d_{i,t-2},$$

and where the parameters of (3) are related to those of (2) as follows

$$\boldsymbol{A}_{i0} = (\boldsymbol{I}_{m_i}, -\boldsymbol{\Lambda}_{i0})\,; \; \boldsymbol{A}_{i1} = \boldsymbol{A}_{i0} + \boldsymbol{\Pi}_i + \boldsymbol{\Gamma}_i; \; \boldsymbol{A}_{i2} = -\boldsymbol{\Gamma}_i; \tag{4}$$

$$\boldsymbol{h}_{i0}^* = \boldsymbol{c}_{i0} + \boldsymbol{c}_{i0}^* \Delta d_{it} + \boldsymbol{c}_{i1}^* \Delta d_{i,t-1} + (-\boldsymbol{\Pi}_i \boldsymbol{\mu}_i)\, d_{i,t-1}; \; \boldsymbol{h}_{i1} = -\boldsymbol{\Pi}_i \boldsymbol{\gamma}_i. \tag{5}$$

where $\boldsymbol{\Pi}_i = \boldsymbol{\alpha}_i \boldsymbol{\beta}_i'$. The extension to higher order VARX* systems is trivial.

The selection of variables used by GNS is based on that of DdPS, but with the exclusion of long-term interest rates and the inclusion of real exports and imports. Therefore, the core variables are the log of real per capita output (y_{it}), the log of the general price level (p_i), the rate of price inflation (Δp_{it}), the log of exports (x_{it}), the log of imports (m_{it}), the short term interest rate (r_{it}), the log of the nominal exchange rate in terms of the US Dollar (e_{it}), the log of real equity prices (q_{it}), and the log of the nominal spot oil price (p_t^o). The corresponding country-specific foreign variables are defined as follows

$$y_{it}^* = \sum_{j=0}^{N} w_{ij} y_{jt};\ p_{it}^* = \sum_{j=0}^{N} w_{ij} p_{jt};\ \Delta p_{it}^* = \sum_{j=0}^{N} w_{ij} \Delta p_{jt};\ x_{it}^* = \sum_{j=0}^{N} w_{ij} x_{jt};\ m_{it}^* = \sum_{j=0}^{N} w_{ij} m_{jt};$$

$$r_{it}^* = \sum_{j=0}^{N} w_{ij} r_{jt};\ e_{it}^* = \sum_{j=0}^{N} w_{ij} e_{jt};\ q_{it}^* = \sum_{j=0}^{N} w_{ij} q_{jt},$$

where w_{ij} is the share of country j in the trade (exports plus imports) of country i such that $w_{ii} = 0$ and $\sum_{j=0}^{N} w_{ij} = 1$. Following DHPS, the log real effective exchange rate, re_{it}, is defined as $ee_{it} + p_{it}^* - p_{it} = \tilde{e}_{it} - \tilde{e}_{it}^*$, where ee_{it} represents the nominal effective exchange rate defined as $\sum_{j=0}^{N} w_{ij} e_{ijt}$. Further details relating to the construction of the dataset may be found in the Data Appendix.

For countries $i = 1, 2, \ldots, 20$,[3] the CVARX* models include the following variables

$$\boldsymbol{x}_{it} = (re_{it}, r_{it}, im_{it}, ex_{it}, q_{it}, \Delta p_{it}, y_{it})' \quad \text{and} \quad \boldsymbol{x}_{it}^* = (p_t^o, r_{it}^*, q_{it}^*, \Delta p_{it}^*, y_{it}^*)'$$

while for countries $i = 21, 22, \ldots, 24$, we have

$$\boldsymbol{x}_{it} = (re_{it}, r_{it}, im_{it}, ex_{it}, \Delta p_{it}, y_{it})' \quad \text{and} \quad \boldsymbol{x}_{it}^* = (p_t^o, r_{it}^*, q_{it}^*, \Delta p_{it}^*, y_{it}^*)'$$

and for Saudi Arabia ($i = 25$) we have

$$\boldsymbol{x}_{25t} = (re_{25t}, im_{25t}, ex_{25t}, \Delta p_{25t}, y_{25t})' \quad \text{and} \quad \boldsymbol{x}_{25t}^* = (p_t^o, r_{25t}^*, q_{25t}^*, \Delta p_{25t}^*, y_{25t}^*)'.$$

The reduced domestic variable sets for these five countries are necessitated by the lack of reliable data. The omission of ex_{it}^* and im_{it}^* from the set of weakly exogenous foreign variables in all cases reflects the fact that the total imports (exports) of country i will be approximately equal to its trade-weighted foreign exports (imports) in a model such as ours with considerable global coverage. Finally, the US model contains the following variables

$$\boldsymbol{x}_{0t} = (p_t^o, r_{0t}, im_{0t}, ex_{0t}, q_{0t}, \Delta p_{0t}, y_{0t})' \quad \text{and} \quad \boldsymbol{x}_{0t}^* = (\tilde{e}_{0t}^*, \Delta p_{0t}^*, y_{0t}^*).$$

[3] See Table 1 for the country order.

The US is considered the reference country in line with DdPS. It is thus assumed that its exchange rate is determined in the remaining N country-specific models representing the rest-of-the-world in the GVAR model; hence the exclusion of re_{0t} from $\boldsymbol{x}_{0t}$ and the inclusion of $\tilde{e}^*_{0t}$ in $\boldsymbol{x}^*_{0t}$. Moreover, following DdPS, r^*_{0t} and q^*_{0t} are not included among the set of weakly exogenous variables as they are unlikely to be weakly exogenous in practice due to the dominant role of the US within the world economy. Similarly, p^o_t is treated as endogenous to the US.

2.2 Global Modelling

The first step in constructing the GVAR model is to collect the $(m+1) \times 1$ vector of the intermediate global variables (where $m = \sum_{i=0}^{N} m_i$)

$$\tilde{\boldsymbol{x}}_t = \left(\tilde{\boldsymbol{x}}'_{0t}, \tilde{\boldsymbol{x}}'_{1t}, ..., \tilde{\boldsymbol{x}}'_{Nt}\right)',$$

where

$$\tilde{\boldsymbol{x}}_{0t} = (\tilde{e}_{0t}, p^o_t, r_{0t}, m_{0t}, x_{0t}, q_{0t}, \Delta p_{0t}, y_{0t})', \;\; \tilde{\boldsymbol{x}}_{it} = (\tilde{e}_{it}, r_{it}, m_{it}, x_{it}, q_{it}, \Delta p_{it}, y_{it})'.$$

It follows that the $\boldsymbol{z}_{it}$'s for each country-specific model can be rewritten as

$$\boldsymbol{z}_{it} = \boldsymbol{W}_i \tilde{\boldsymbol{x}}_t, \;\; i = 0, 1, ..., N, \tag{6}$$

where the $\boldsymbol{W}_i$'s are $(m_i + m^*_i) \times (m+1)$ link matrices defined in terms of bilateral trade-weights retrieved from the IMF's DOTS database. The construction of the link matrices will be discussed in detail below. It is now straightforward to re-write (3) in stacked form as

$$\boldsymbol{H}_0 \tilde{\boldsymbol{x}}_t = \boldsymbol{h}^*_0 + \boldsymbol{h}_1 t + \boldsymbol{H}_1 \tilde{\boldsymbol{x}}_{t-1} + \boldsymbol{H}_2 \tilde{\boldsymbol{x}}_{t-2} + \boldsymbol{u}_t, \tag{7}$$

where

$$\underset{m\times(m+1)}{\boldsymbol{H}_0} = \begin{pmatrix} \boldsymbol{A}_{00}\boldsymbol{W}_0 \\ \boldsymbol{A}_{10}\boldsymbol{W}_1 \\ \vdots \\ \boldsymbol{A}_{N0}\boldsymbol{W}_N \end{pmatrix}; \;\; \underset{m\times(m+1)}{\boldsymbol{H}_1} = \begin{pmatrix} \boldsymbol{A}_{01}\boldsymbol{W}_0 \\ \boldsymbol{A}_{11}\boldsymbol{W}_1 \\ \vdots \\ \boldsymbol{A}_{N1}\boldsymbol{W}_N \end{pmatrix}; \;\; \underset{m\times(m+1)}{\boldsymbol{H}_2} = \begin{pmatrix} \boldsymbol{A}_{02}\boldsymbol{W}_0 \\ \boldsymbol{A}_{12}\boldsymbol{W}_1 \\ \vdots \\ \boldsymbol{A}_{N2}\boldsymbol{W}_N \end{pmatrix},$$

$$\boldsymbol{h}_0^* = \begin{pmatrix} \boldsymbol{h}_{00}^* \\ \boldsymbol{h}_{10}^* \\ \vdots \\ \boldsymbol{h}_{N0}^* \end{pmatrix}; \ \boldsymbol{h}_1 = \begin{pmatrix} \boldsymbol{h}_{01} \\ \boldsymbol{h}_{11} \\ \vdots \\ \boldsymbol{h}_{N1} \end{pmatrix}; \ \boldsymbol{u}_t = \begin{pmatrix} \boldsymbol{u}_{0t} \\ \boldsymbol{u}_{1t} \\ \vdots \\ \boldsymbol{u}_{Nt} \end{pmatrix}.$$

DHPS and GNS note that the omission of $\tilde{e}_{0t}$ from the US variables coupled with its inclusion in $\tilde{\boldsymbol{x}}_t$ necessitates the imposition of a further restriction in order to achieve a unique solution for $\tilde{\boldsymbol{x}}_t$ on the basis of the country-specific models. This additional restriction is derived from the definition of the US$ exchange rate *vis-à-vis* the US$. Hence, $e_{0t} = 0$ which implies that $\tilde{e}_{0t} = -p_{0t}$. Therefore, we may define the $m \times 1$ vector of global variables as

$$\tilde{\boldsymbol{x}}_t = \left(\mathring{\boldsymbol{x}}_{0t}', \tilde{\boldsymbol{x}}_{1t}', ..., \tilde{\boldsymbol{x}}_{Nt}'\right)', \ \mathring{\boldsymbol{x}}_{0t} = (p_t^o, r_{0t}, m_{0t}, x_{0t}, q_{0t}, p_{0t}, y_{0t})'.$$

The implication of this final restriction is that while we are solving for price-level inflation in countries $i = 1, ..., N$, we are solving for the price-level itself in the US. This necessitates the following transformation

$$\tilde{\boldsymbol{x}}_t = \boldsymbol{S}_0\boldsymbol{x}_t - \boldsymbol{S}_1\boldsymbol{x}_{t-1}, \tag{8}$$

where $\boldsymbol{S}_0$ and $\boldsymbol{S}_1$ are $(m+1) \times m$ selection matrices of the following form

$$\boldsymbol{S}_0 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & -1 & 0 & \mathbf{0} \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \boldsymbol{I}_{m-m_0} \end{pmatrix}, \ \boldsymbol{S}_1 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & \mathbf{0} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0}_{m-m_0} \end{pmatrix}$$

The second order structural GVAR model may now be written as

$$\boldsymbol{F}_0\boldsymbol{x}_t = \boldsymbol{h}_0^* + \boldsymbol{h}_1 t + \boldsymbol{F}_1\boldsymbol{x}_{t-1} + \boldsymbol{F}_2\boldsymbol{x}_{t-2} + \boldsymbol{F}_3\boldsymbol{x}_{t-3} + \boldsymbol{u}_t, \tag{9}$$

where $\boldsymbol{F}_0 = \boldsymbol{H}_0\boldsymbol{S}_0$, $\boldsymbol{F}_1 = \boldsymbol{H}_1\boldsymbol{S}_0 + \boldsymbol{H}_0\boldsymbol{S}_1$, $\boldsymbol{F}_2 = \boldsymbol{H}_2\boldsymbol{S}_0 - \boldsymbol{H}_1\boldsymbol{S}_1$, and $\boldsymbol{F}_3 = -\boldsymbol{H}_2\boldsymbol{S}_1$.

The reduced-form GVAR is obtained by pre-multiplying throughout by $\boldsymbol{F}_0^{-1}$ yielding:

$$\boldsymbol{x}_t = \boldsymbol{g}_0^* + \boldsymbol{g}_1 t + \boldsymbol{G}_1 \boldsymbol{x}_{t-1} + \boldsymbol{G}_2 \boldsymbol{x}_{t-2} + \boldsymbol{G}_3 \boldsymbol{x}_{t-3} + \boldsymbol{\varepsilon}_t, \tag{10}$$

where $\boldsymbol{G}_j = \boldsymbol{F}_0^{-1} \boldsymbol{F}_j$, $j = 1, 2, 3$, $\boldsymbol{g}_0^* = \boldsymbol{F}_0^{-1} \boldsymbol{h}_0^*$, $\boldsymbol{g}_1 = \boldsymbol{F}_0^{-1} \boldsymbol{h}_1$, and $\boldsymbol{\varepsilon}_t = \boldsymbol{F}_0^{-1} \boldsymbol{u}_t$. Although the model is estimated on a country-by-country basis, the shocks may be weakly correlated across countries. Specifically, it is assumed that $E\left(\boldsymbol{u}_{it} \boldsymbol{u}_{jt}'\right) = \boldsymbol{\Sigma}_{u,ij}$ for $t = t'$ and 0 otherwise. Global interactions take place through three distinct but interrelated channels: (i) direct dependence of $\boldsymbol{x}_{it}$ on $\boldsymbol{x}_{it}^*$ and its lagged values, (ii) dependence of the country-specific variables on common global exogenous variables such as the crude oil price, and (iii) non-zero contemporaneous dependence of shocks in country i on shocks in country j, measured via the cross country covariances, $\boldsymbol{\Sigma}_{u,ij}$. Finally, as shown by DdPS, the GVAR model admits both intra- and inter-country cointegration. Note that the cointegration properties of the individual country-specific models are preserved in GVAR and thus the mean-reverting features of the individual economies carry over to the world economy.

2.3 Link matrices

Careful construction of the link matrices used in (6) fundamentally underpins the GVAR framework. In GNS, the $\boldsymbol{W}_i$'s are defined as follows:

$$\underset{10\times 177}{\boldsymbol{W}_0} = \begin{pmatrix} \boldsymbol{R}_{00} & \mathbf{0}_{7\times 7} & \cdots & \mathbf{0}_{7\times 7} & \mathbf{0}_{7\times 6} & \cdots & \mathbf{0}_{7\times 6} & \mathbf{0}_{7\times 5} \\ \mathbf{0}_{3\times 8} & \boldsymbol{W}_{01} & \cdots & \boldsymbol{W}_{0,20} & \boldsymbol{W}_{0,21} & \cdots & \boldsymbol{W}_{0,24} & \boldsymbol{W}_{0,25} \end{pmatrix},$$

$$\underset{12\times 177}{\boldsymbol{W}_i} = \begin{pmatrix} \boldsymbol{R}_{i0} & \boldsymbol{R}_{i1} & \boldsymbol{R}_{i2} & \cdots & \boldsymbol{R}_{i,25} \\ \boldsymbol{W}_{i0} & \boldsymbol{W}_{i1} & \boldsymbol{W}_{i2} & \cdots & \boldsymbol{W}_{i,25} \end{pmatrix}, \; i = 1, ..., 25,$$

where

$$\boldsymbol{R}_{00} = \begin{bmatrix} \mathbf{0}_{7\times 1} & \boldsymbol{I}_7 \end{bmatrix}, \; \boldsymbol{R}_{i0} = \begin{bmatrix} -w_{i0} & \mathbf{0}_{1\times 7} \\ \mathbf{0}_{6\times 1} & \mathbf{0}_{6\times 7} \end{bmatrix}, \; i = 1, ..., 25,$$

$$\{\boldsymbol{R}_{ij}\}_{j=1}^{20} = \left\{ \begin{array}{cc} \begin{bmatrix} -w_{ij} & \mathbf{0}_{1\times 6} \\ \mathbf{0}_{6\times 1} & \mathbf{0}_{6\times 6} \end{bmatrix} & \text{if } j \neq i \\ \boldsymbol{I}_7 & \text{if } j = i \end{array} \right\}, \; i = 1, ..., 25,$$

$$\{\boldsymbol{R}_{ij}\}_{j=21}^{24} = \left\{ \begin{array}{cc} \begin{bmatrix} -w_{ij} & \mathbf{0}_{1\times 5} \\ \mathbf{0}_{6\times 1} & \mathbf{0}_{6\times 5} \end{bmatrix} & \text{if } j \neq i \\ \boldsymbol{I}_6 & \text{if } j = i \end{array} \right\}, \; i = 1, ..., 25,$$

$$\boldsymbol{R}_{i,25} = \left\{ \begin{array}{cc} \begin{bmatrix} -w_{i,25} & \mathbf{0}_{1\times 4} \\ \mathbf{0}_{6\times 1} & \mathbf{0}_{6\times 4} \end{bmatrix} & \text{if } i \neq 25 \\ \boldsymbol{I}_5 & \text{if } i = 25 \end{array} \right\},$$

$$\{\boldsymbol{W}_{0j}\}_{j=1}^{20} = \begin{bmatrix} w_{0j} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & w_{0j} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & w_{0j} \end{bmatrix},$$

$$\{\boldsymbol{W}_{0j}\}_{j=21}^{24} = \begin{bmatrix} w_{0j} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & w_{0j} & 0 \\ 0 & 0 & 0 & 0 & 0 & w_{0j} \end{bmatrix}, \ \boldsymbol{W}_{0,25} = \begin{bmatrix} w_{0,25} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & w_{0,25} & 0 \\ 0 & 0 & 0 & 0 & w_{0,25} \end{bmatrix},$$

and for $i = 1, ..., 25$,

$$\boldsymbol{W}_{i0} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & w_{i0}^{*} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & w_{i0}^{**} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & w_{i0} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{i0} \end{bmatrix}, \ \{\boldsymbol{W}_{ij}\}_{j=1}^{20} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & w_{ij}^{*} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & w_{ij}^{**} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & w_{ij} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & w_{ij} \end{bmatrix},$$

$$\{\boldsymbol{W}_{ij}\}_{j=21}^{24} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & w_{ij}^{*} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & w_{ij} & 0 \\ 0 & 0 & 0 & 0 & 0 & w_{ij} \end{bmatrix}, \ \boldsymbol{W}_{i,25} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & w_{i,25} & 0 \\ 0 & 0 & 0 & 0 & w_{i,25} \end{bmatrix}.$$

The w_{ij}'s denote the weight of country i in the trade of country j. Similarly, the w_{ij}^{*}'s denote the weight of country i in the trade of country j after adjusting appropriately for the lack of Saudi interest rate data. Finally, the w_{ij}^{**}'s represent the weight of country i in the trade of country j adjusted to account for the omission of the stock index for China, Indonesia, Peru and Turkey and Saudi Arabia. By construction, $\sum_{j=0}^{N} w_{ij} = \sum_{j=0}^{N} w_{ij}^{*} = \sum_{j=0}^{N} w_{ij}^{**} = 1$, and $w_{ii} = w_{ii}^{*} = w_{ii}^{*} = 0 \ \forall i$.

As in DdPS, GNS define the 26×26 trade-weight-based link matrices using bilateral trade averages reported in the IMF's DOTS database over the period 1999-2001. Preliminary estimation results using trade averages defined over different windows and also using time-varying trade weights yield qualitatively similar results; therefore the weighting scheme used in DdPS is retained to maintain closer comparability with their results.

2.4 Dynamic analysis of the GVAR model

While the focus of GNS is on scenario-based probabilistic forecasting, our focus here is on the analysis of generalised impulse response functions (GIRFs) and generalised forecast error variance decompositions (GFEVDs). The order-invariance of the generalised approach to dynamic analysis is important in the context of GVAR models, as deriving a robust structural factorisation of the contemporaneous matrix would be highly challenging given the dimensionality of the system, as would achieving an uncontroversial Wold-causal ordering of the global variables. Therefore, we will abstract from the case of structurally identified shocks herein.

DHPS discuss the extension of the standard tools of dynamic analysis in VAR to the global VAR context. The starting point is the MA(∞) representation of the GVAR model, (10)

$$\boldsymbol{x}_t = \boldsymbol{d}_t + \sum_{j=0}^{\infty} \boldsymbol{B}_j \boldsymbol{\varepsilon}_{t-j}, \tag{11}$$

where $\boldsymbol{d}_t$ represents the deterministic component of $\boldsymbol{x}_t$ and $\boldsymbol{B}_j$ is evaluated recursively as follows

$$\boldsymbol{B}_j = \boldsymbol{G}_1 \boldsymbol{B}_{j-1} + \boldsymbol{G}_2 \boldsymbol{B}_{j-2} + \boldsymbol{G}_3 \boldsymbol{B}_{j-3},\ j = 1, 2, \text{with } \boldsymbol{B}_0 = \boldsymbol{I}_m,\ \boldsymbol{B}_j = \boldsymbol{0} \text{ for } j < 0.$$

The generalised impulse response function (GIRF) representing the time profile of the effect of a one unit (one standard error) shock to the ℓth element of $\boldsymbol{x}_t$ on the jth element of $\boldsymbol{x}_t$ is given by

$$GIRF\left(x_{jt}; u_{\ell t}, n\right) = \frac{\boldsymbol{e}_j' \boldsymbol{B}_n \boldsymbol{F}_0^{-1} \boldsymbol{\Sigma}_u \boldsymbol{e}_\ell}{\sqrt{\boldsymbol{e}_\ell' \boldsymbol{\Sigma}_u \boldsymbol{e}_\ell}},\ n = 0, 1, 2, ...,\ j, \ell = 1, ..., m. \tag{12}$$

where $\boldsymbol{e}_j$ is an $m \times 1$ selection vector whose jth element is equal to unity with zeros elsewhere (similarly for $\boldsymbol{e}_\ell$). In the GVAR model, this expression may be used to compute the effects of shocking any chosen endogenous variable on any or all of the global endogenous variables at any desired horizon.[4]

Forecast error variance decomposition in the context of VAR models is typically performed on a set of orthogonalised shocks derived from Choleski decomposition of the variance matrix,

[4] Note that the GIRF of a unit shock to the US price-level can be converted to that of a shock to US inflation simply by first-differencing.

where the contribution of the jth orthogonalised innovation to the mean squared error of the n-step ahead forecast is computed (e.g. Diebold and Yilmaz , 2009). However, in the context of a GVAR model involving multiple variables for multiple countries, it is generally infeasible to find a causal ordering such that the shocks across countries and variables can be assumed to be orthogonal. We therefore have recourse to GFEVDs, which are order-invariant and are computed by conditioning on non-orthogonalised shocks, u_{jt}, u_{jt+1},..., u_{jt+n} for $j = 1, ..., m$. The GFEVD representing the proportion of the n-step ahead forecast error variance of the ℓth element of $\boldsymbol{x}_t$ accounted for by the innovation in the jth element of $\boldsymbol{x}_t$ is written as

$$GFEVD\left(x_{\ell t}; u_{jt}, n\right) = \frac{\sigma_{u,jj}^{-1} \sum_{h=0}^{n} \left(\boldsymbol{e}_{\ell}' \boldsymbol{B}_h \boldsymbol{F}_0^{-1} \boldsymbol{\Sigma}_u \boldsymbol{e}_j\right)^2}{\sum_{h=0}^{n} \boldsymbol{e}_{\ell}' \boldsymbol{B}_h \boldsymbol{F}_0^{-1} \boldsymbol{\Sigma}_u \boldsymbol{F}_0^{-1\prime} \boldsymbol{B}_h' \boldsymbol{e}_{\ell}}, \; n = 0, 1, 2, ..., \; \ell = 1, ..., m, \tag{13}$$

It is important to note that the non-diagonality of $\boldsymbol{\Sigma}_u$ implies that the elements of $GFEVD\left(x_{\ell t}; u_{jt}, n\right)$ need not sum to unity across j. Hence, we follow Diebold and Yilmaz (2011) and define the *normalized* GFEVD as

$$\eta_{\ell j} = \frac{GFEVD\left(x_{\ell t}; u_{jt}, n\right)}{\sum_{\ell=1}^{m} GFEVD\left(x_{\ell t}; u_{jt}, n\right)}$$

from which it follows trivially that

$$\sum_{\ell=1}^{m} \eta_{\ell j} = 1 \text{ and } \sum_{j=1}^{m} \sum_{\ell=1}^{m} \eta_{\ell j} = m$$

One significant benefit of normalizing such that the sum of the forecast error variance shares of each variable is equal to 100% is that it eases the interpretation of the GFEVDs and improves the robustness of the analysis where large scale differences are present between variances.

3 Preliminary Analysis

The GNS model is estimated over the period 1980Q2–2007Q2 for the set of 33 countries (26 regions) identified in Table 1 (details of the dataset and its construction may be found in the Appendix). Tables 2 and 3 provide summary statistics of real output growth, inflation and the balance of trade, which may be considered the three key macroeconomic indicators in the dataset. A number of well-known stylised facts are readily apparent in the data.

[Insert Tables 2 and 3 about here]

Firstly, it is apparent that the level and volatility of the average real output growth rate varies substantially across countries. The average real output growths of developed countries lie in the range 2-3.5% per annum (e.g. 3.05% for the U.S., 2.17% for the Eurozone, 2.58% for Japan, 2.57% for the UK, 2.76% for Canada and 3.26% for Australia). The emerging economies of Asia have enjoyed considerably faster growth, typically between 5 and 7% (e.g. 6.43% for Korea, 5.97% for India, 6.76% for Singapore and 5.69% for Thailand). The two exceptions are China with the highest growth rate of 9.48%, and the Philippines exhibiting slow growth at just 2.99%. Among the remaining countries, Turkey and Chile have relatively high growth rates of approximately 4.4% per annum, compared to an average of just 2%. The real output growths of developed countries are relatively stable, with standard deviations between 2% and 4%, while standard deviations between 6% and 12% typify the emerging and developing countries. Interestingly, China has enjoyed the most rapid growth (9.48%) in conjunction with volatility comparable to that of a developed economy (3.16%).

Historical accounts of inflation among the 26 countries/regions are summarised in Table 2. The most striking feature is that average rates of inflation in almost all countries are considerably higher than those experienced in recent years. This observation is often attributed to the widespread adoption of inflation-targeting monetary policy regimes in recent years. The developed economies have the lowest and most stable inflation rates on average, ranging from 2% to 5% (e.g. 3.45% for the US, 3.41% for Eurozone, 0.99% for Japan and 4.18% for the UK). The Japanese figure is somewhat misleading, deriving largely from the post-1990 deflationary era. The emerging Asian economies have experienced slightly higher average inflation rates, mostly of the order of 5-8%. In particular, the figures for China and Korea are approximately 5% and that of India is 7.54%. Singapore and Saudi Arabia are notable for their low inflation rates, at 1.67% and 0.51%, respectively. The Latin American countries and Turkey suffered hyperinflation during the sample period which are both high and extremely volatile. Specifically, the average inflation rates are 97.43% for Brazil, 70.19% for Argentina, 66.93% for Peru and 40.10% for Turkey. Inflation peaked in Argentina at 759.22% in 1989Q3, 622.61% in Brazil in 1990Q1 and 856.53% in 1990Q3 in Peru.

Table 3 summarises the real export and import performance of countries. Similar to the patterns observed for real output growth and inflation, the industrialised countries have experienced lower and more stable average export and import growth, typically in the range 1-3%.

Emerging and developing economies exhibit higher but more volatile growth rates. For example, the average export and import growth rates are 16.13% and 14.02% for China, 9.02% and 8.56% for India, 8.18% and 6.97% for Korea, 10.01% and 8.23% for Thailand, and 9.70% and 7.78% for Turkey. Table 3 also demonstrates the often large and persistent current account deficits that characterise many of the more developed countries. In particular, the US, UK, Australia, and New Zealand experience average growth rates of trade deficit of 1.49%, 1.09%, 0.68% and 0.80%, respectively. However, this trend is not universal, with the Eurozone, Japan, Norway, Sweden and Switzerland all experiencing average growth rates of trade surplus of 0.50%, 0.98%, 1.66%, 1.05% and 0.96%, respectively. Almost all of the emerging and developing economies enjoy trade surpluses. China, Korea and Singapore have relatively high growth rates of trade surplus of 2.11%, 1.20% and 1.26%, respectively, reflecting their export-led growth strategies.

3.1 Pre-Testing Results

GNS verify that the overwhelming majority of the series used in estimation follow non-stationary $I(1)$ processes. Furthermore, GNS find that the hypothesis that the foreign regressors are weakly exogenous cannot generally be rejected at the 5% level. These findings are not surprising but they are important, as they underpin the cointegrating GVAR model. Of more interest, however, are the structural break tests conducted in GNS. Given our emphasis on intertemporal effects and our belief that many of the World's economies have been subject to significant shocks that may have altered the behaviour of their core variables as well as the relationships among them, testing for structural breaks is of paramount importance. Where the impact of a break is substantial (e.g. the 1997 Asian crisis), the choice of whether or not to include break dummies in the country-specific models will have a profound effect on both the cointegrating relationships in the model and its performance in terms of dynamic analysis. Balancing this argument, however, one must also bear in mind that the impact of structural breaks may be attenuated to some degree in the global system due to co-breaking behaviour.

In GNS, we adopt a simple and pragmatic approach to structural break testing based on CUSUM tests of the country-specific VECM models. The main limitation of the treatment of structural breaks is that each country-specific model allows for only a single one-time permanent intercept shift that occurs at the same time for all of the domestic endogenous variables in that country. Therefore, it is necessary to interpret the statistical evidence of breaks derived from the formal testing procedure with care and select 'consensus' break points which may be considered to be significant events which have had repercussions for the entire economy. Table 1 summarises the timing and probably cause of our selected structural breaks. GNS find substantial support for a break in 1997Q3/4 for the South-East Asian bloc relating to the financial crisis (in particular inflation and output show a noticeable perturbation).[5] Similarly, the South American economies generally exhibit striking breaks associated with dollarisation (interest rates, exchange rates and inflation are typically profoundly effected). Careful analysis also suggests that the departure of the UK from the ERM had significant repercussions for the domestic economy as of 1992Q4 and that the real-estate and stock-market crash in Japan caused a break at 1990Q1. Lastly, the composite Eurozone economy reacts noticeably to the introduction of the Euro in 1999Q1, with imports, exports and the exchange rate showing the strongest response.

4 Generalized Impulse Response Analysis

As a first step in our analysis of the international linkages of the Korean macroeconomy, we consider the effect of a number of economically interesting scenarios by means of generalized impulse response analysis. More specifically, we consider an oil price shock, a US interest rate shock, a US stock market shock, a Chinese inflationary shock and a Korean interest rate shock. All the shocks are of one standard error in magnitude. Where possible, comparisons will be drawn between our findings and the results derived from Shin's (2009) national model. In general, one would expect to see some differences between the results of the two models for a variety of reasons. Firstly, the models are estimated on different datasets.[6] Secondly, Shin considers only the three shocks to oil price, foreign and domestic monetary policy, and reports structural as opposed to generalised impulse response functions under the assumption that $r = 5$ rather than $r = 4$, as is the case here. Finally, the GVAR model accounts for inter-country linkages in a sophisticated manner of which the national model is inherently incapable.

[5] Notice that in the Korean national model developed by Shin (2009), a one-time permanent intercept shift is included at 1997Q4.

[6] Shin (2009) defines $\boldsymbol{x}_t = (e_t, r_t, \Delta p_t, y_t, pps_t, h_t)'$ and $\boldsymbol{x}_t^* = (p_t^o, r_t^*, y_t^*)'$, where h_t is the log of the money-output ratio and $pps_t = p_t - p_t^*$ is the relative price. An additional difference lies in the construction of foreign variables. In particular, r_t^* is proxied by the US interest rate while both p^* and y_t^* are constructed using the OECD aggregate measures.

4.1 Oil Price Shock

Figure 1 shows the effect of a positive oil price shock on each of the Korean domestic variables, as well as the trade balance defined as $TB = X - M$. Inflation increases immediately as one might expect, although it decreases in the second quarter before increasing again in the third quarter. At longer horizons, the inflationary response becomes negative. This negative long-run response may, in turn, result from the positive response of the interest rate to the shock, which is suggestive of early monetary tightening by the Bank of Korea to prevent higher oil prices leading to rising inflation. These findings contrast somewhat with those of Shin (2009), where an oil price shock is found to have a negligible effect on inflation and interest rates at all horizons. One interesting possibility is that the Korean government's history of intervening in petroleum markets may have insulated the economy from the expected inflationary effects of oil price rises.

As expected, the shock has a strong negative effect on output, both on impact and in the medium- to long-run, reaching a trough after 8 quarters. A similar result is achieved by Shin (2009). Similarly, the stock market response is strongly negative reflecting a generalised reduction in the expected discounted profits of Korean firms. The import response is initially positive reflecting the higher cost of oil imports in the short-term but then decreases and settles at a negative value in the long-run. This pattern suggests that oil demand in Korea is somewhat elastic but that Korean households and firms adjust their resource consumption gradually. Meanwhile, the export response is negative throughout. Furthermore, since the response of exports dominates that of imports in absolute value, the trade balance deteriorates at all horizons. Finally, the real exchange rate decreases (i.e. appreciates) on impact before gradually depreciating and settling at a weaker value in the long-run. This long-run depreciation is again comparable with the result from Shin's national CVAR model.

[Insert Figure 1 about here]

4.2 US Interest Rate Shock

Figure 2 plots the impulse responses of the Korean domestic variables with respect to a positive US interest rate shock (indicating the US contractionary monetary policy). The US monetary shock seems to have very small impacts on domestic interest rate, output and inflation in comparison with the effects on the nominal exchange rate and other domestic variables. As expected, however, the Korean interest rate responds positively following the shock given the pre-eminent role of US securities in global financial markets. The shock is associated with a gradual appreciation of the real exchange rate which is maintained in the long-run. This pattern is qualitatively consistent with that documented by Shin, in which he also notes that the decreases in relative price and domestic real money balance might help explain the appreciation. It is likely that this appreciation exerts upward pressure on imports and downward pressure on exports, and this provides a plausible explanation of the observed negative response of the trade balance following the shock. Meanwhile, output growth falls in the short- to medium-term, reflecting the close linkage between exports and economic activity in the Korean macroeconomy. Interestingly, the effect of the shock on inflation is positive at all horizons. This finding contrasts with Shin (2009) who finds that the US monetary shock will lower inflation rates at all horizons, albeit negligibly small. On one hand, this may simply be a manifestation of the well-known empirical price puzzle. On the other hand, it could be at least partially the result of cost-push inflationary pressures if leveraged firms pass a significant proportion of the cost increases resulting from higher domestic and, especially, foreign interest rates on to their customers. Finally, the response of the stock market is also positive at all horizons. It is a widely-held belief that equity prices respond negatively to interest rate innovations as the latter increases the discount factor applied to future earnings. However, stock markets may in fact record gains following interest rate hikes if investors move from bonds to equity as higher yields depress bond prices.

[Insert Figure 2 about here]

4.3 US Stock Market Shock

Figure 3 shows the impact of a positive US stock market shock. The Korean stock market response is relatively strong and positive on impact before it intensifies and reaches a peak after 5 quarters, after which it gradually eases toward a long-run positive value. The positive response of the KOSPI on impact reflects the sensitivity of Korean financial markets to conditions in the major world markets. This is a clear manifestation of the profound global financial linkages that have developed in the era of globalisation. However, the strengthening of the KOSPI's response over the following four quarters is also suggestive of significant real linkages between the US and Korea deriving from the strong bilateral trade links between the two countries coupled with Korea's export-oriented growth strategy.

Considerable evidence of these trade linkages may be found in the responses of output, inflation, exports and imports. In all cases, we observe a positive impact response followed by convergence to a positive long-run value. Interestingly, the GIRFs for imports and exports peak at 7 quarters while output growth peaks at 5 quarters, roughly coinciding with the peak equity response. Since the growth in imports exceeds that in exports, the trade balance actually deteriorates somewhat following the shock. Meanwhile, the interest rate response is initially negligible before gradually increasing and settling at a long-run positive value, reflecting the policy response to elevated inflationary pressure. Finally, the real exchange rate experiences a mild appreciation consistent with the higher level of the interest rate.

[Insert Figure 3 about here]

4.4 Chinese Inflationary Shock

Figure 4 plots the impulse responses associated with elevated Chinese inflationary pressure. Given the growing importance of China within the world economy and the close trading relationship between Korea and China, such a shock may be expected to exert a significant influence on the Korean macroeconomy and our results confirm this hypothesis. Inflation increases sharply following the shock and further overshoots into the second quarter before settling at a value close to zero in the long-run. Meanwhile, the interest rate response is suggestive of anti-inflationary monetary policy as the interest rate increases after a modest lag and is maintained at a higher level into the long-run. The maintenance of higher domestic interest rates presumably contributes to the observed appreciation of the Korean Won following the shock. In turn, the strengthening of the Won is likely to explain a large proportion of the observed decline in real exports. Meanwhile, real imports also decline. This probably reflects a combination of factors, including reduced demand for imported intermediate inputs used by exporting industries and the higher price of imported goods from China (and other countries to which the Chinese inflation has been passed on). Interestingly, despite the deterioration in the trade balance, the shock exerts a positive influence on both output growth and the stock market in the short- to medium-term.

[Insert Figure 4 about here]

4.5 Korean Interest Rate Shock

Figure 5 plots the impulse responses following a positive Korean interest rate shock. The response of inflation on impact is positive but thereafter a small negative response is observed.

Interestingly, the shock is found to exert an expansionary effect on real output. This is an unexpected finding but it is consistent with Shin (2009), who finds a positive output response for the first five quarters after the shock, and attributes this finding to the suboptimal conduct of domestic monetary policy in the years leading up to the Asian Financial Crisis.

The real exchange rate appreciates on impact and further overshoots in the second quarter before gradually converging to a stronger value in the long-run. This pattern closely matches that documented by Shin, which he notes is generally consistent with Dornbusch's (1976) overshooting model, which predicts a large initial appreciation following a monetary tightening followed by subsequent depreciation to its long-run level. The response of real imports is positive on impact reflecting the strengthening of the Won, but it then turns negative from the second quarter. Meanwhile, the strengthening of the currency contributes to the negative response of real exports at all horizons. Overall, therefore, the response of the trade balance is also negative. Finally, the stock market contracts in the short- to medium-term before a significant positive response emerges in the long-run. This is consistent with Shin's (2009, p.222) observation that interest rates remained relatively high even in the boom phase before the crisis.

[Insert Figure 5 about here]

5 Forecast Error Variance Decomposition

In this Section, we seek to understand which global variables exert a dominant influence on a selection of key economic indicators for Korea by use of normalised GFEVDs. However, the GFEVDs derived from the basic GNS model are often somewhat distorted in the sense that the top 10 contributors to the forecast error variance for a given variable over a given horizon may be rather diversely distributed. For example, in the case of Korea, it is not uncommon to observe variables from relatively peripheral countries such as Argentina, Australia, Brazil, Canada, Chile, Malaysia, Mexico, Peru, Singapore, South Africa, Sweden and Thailand among the main contributors.

These results suggest that many of the off-diagonal blocks in Σ_u may be imprecisely estimated or statistically insignificant due to the relatively high dimensionality of the GVAR model. This is likely to be especially true of those blocks associated with small and/or developing countries and regions. A simple and parsimonious solution to this issue is to impose block diagonality in Σ_u, such that the global covariance matrix is defined as follows

$$\Sigma_u = \begin{bmatrix} \Sigma_{u,00} & 0 & \cdots & 0 \\ 0 & \Sigma_{u,11} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \Sigma_{u,NN} \end{bmatrix}$$

While this may at first glance seem to impose onerous restrictions on the degree to which international linkages are captured in the model, note that the direct impacts of the weighted average of the foreign variables have already been incorporated in the estimation of the country-specific VAR parameters. Therefore, in this Section, we report the results obtained using the block-diagonal covariance matrix.[7]

Figure 6 reports a simplified summary of the normalized GFEVDs for each of the Korean domestic variables. In each case, the normalized forecast error variance (FEV) is decomposed into four components as follows:

own the proportion of the variable's FEV explained by the variable itself

other_dom the proportion explained by the remaining domestic variables

oil the proportion explained by the oil price

foreign the proportion explained by all foreign variables excluding oil

A number of interesting patterns emerge. Firstly, the own contribution is typically dominant in the short horizon but its importance fades rapidly as the horizon increases. The only case where this pattern is noticeably less prevalent is the real exchange rate. Secondly, the combined contribution of oil and foreign variables increases markedly with the horizon in all cases except the interest rate (where it remains relatively constant throughout) and the real exchange rate (where it starts at a very high level and the decreases somewhat). Finally, the contribution of the oil price becomes very large in the case of real exports, equity prices and real output but plays a much less prevalent role in the remaining cases.

[Insert Figure 6 about here]

[7] Comprehensive tables of the generalised FEVDs derived from the GVAR model and orthogonalised and generalised FEVDs based on the country-specific models are available upon request. In future work it would be interesting to consider an intermediate case based on formal tests of cross-section dependence, but this is beyond the scope of the current paper.

Panel (a) of Figure 6 shows the time profile of our decomposition for the real exchange rate. The own contribution (i.e. the proportion of the real exchange rate FEV accounted for by the real exchange rate) starts at 22% at the one quarter horizon before gradually diminishing to 11% after twelve quarters. Meanwhile, the total contribution of the other domestic variables increases from 8% to 21% over the same time frame, with the most significant contributions coming from the stock market, the interest rate and real exports. The contribution of the oil price is small at all horizons, averaging just 1.75% over twelve quarters. The remainder of the FEV (totalling more than 50% at all horizons up to twelve quarters) is therefore accounted for by conditions in Korea's overseas trading partners. This is an intuitively pleasing finding in the case of a small, open and export-oriented economy such as Korea. Interestingly, Japanese real exchange rates, exports and imports are significant contributors to the FEV in the shorter horizons but their influence diminishes at longer horizons, being supplanted notably by Chinese and European variables. US output is also found to exert a non-negligible influence on the Korean real exchange rate, particularly at longer horizons.

Panel (b) reports the case of the interest rate. In this case, the own contribution decreases from 67% at the one quarter ahead horizon to just 9% after 12 quarters. Meanwhile, the equivalent values for the contribution of the remaining domestic variables are 6% and 61%. Overall, therefore, the total domestic contribution to the FEV remains remarkably constant at roughly 70% across all horizons. A plausible explanation of this finding is that it simply reflects the domestic focus of the Korean monetary policy. Once again, oil prices play a peripheral role, while the most important foreign contributors to the interest rate FEV are the US and European stock markets and Chinese inflation, each of which may be expected to influence Korean price level inflation in a relatively straightforward manner.

Panels (c) and (d) relate to real imports and real exports. In each case, we observe a significant own contribution at the one quarter ahead horizon of the order of 60%. This diminishes rapidly in both cases but more significantly for exports, where the own contribution after 12 quarters is just 5.5% as opposed to 23.5% for real imports. Meanwhile, the contribution of the other domestic variables is broadly similar, but is slightly larger on average in the case of real exports. The most important domestic variable for imports is inflation, while for exports it is the real exchange rate. Both results highlight the importance of relative purchasing power concerns for the trade variables. One interesting difference between the figures is the relative contribution of the oil price to the respective import and export FEVs. At shorter horizons, the contribution of the oil price is small or even negligible in both cases. However, while it remains fairly small for imports this is not true of exports where it reaches 20% after 12 quarters. As mentioned above, government intervention in energy markets may explain the relatively muted effect of the oil price on imports. Finally, the contribution of the non-oil foreign variables increases from approximately 10% at the one quarter horizon to roughly 50% after 12 quarters. The most important foreign contributors to the import FEV are US equity prices, output and prices, Chinese output and European equity prices. Similarly, the same three US macroeconomic variables account for the majority of non-oil foreign contributions to the export FEV.

Panel (e) shows results for the Korean stock market FEV. In this case, the own contribution declines smoothly from 58% to 21% after 12 quarters while the contribution of the other domestic variables remains relatively muted, averaging just 8% over the 12 quarter horizon. This suggests that domestic economic conditions do not exert a dominant influence on the performance of the KOSPI which, in turn, is suggestive of the index's rapid integration into the global financial system, especially after the IMF bailout program suffered during the Asian crisis period. The contribution of the oil price to the equity FEV is significant at all horizons, starting at 6% and climbing to 34% after 12 quarters. This clearly reflects the considerable energy intensity of economic activity in Korea coupled with its reliance on imported oil. Finally, the contribution of the non-oil foreign variables is substantial at all horizons and becomes the dominant influence on the equity FEV at the four quarter ahead horizon and beyond. The most important foreign variables are US equity prices, consumer prices, imports and exports, as well as European equity prices. Furthermore, Japanese equity prices play a non-negligible role at shorter horizons, accounting for more than 3% of the one quarter ahead equity FEV. These results suggest that not only is the KOSPI relatively insensitive to domestic economic conditions but it is highly sensitive to conditions in the World's dominant markets.

Panel (f) shows the results for inflation. The own contribution falls sharply from 61% at the one quarter ahead horizon to just 9% at the two quarter ahead horizon before it settles at roughly 16.5% in the longer horizons. The contribution of the other domestic variables grows substantially from 7% to 28% over the same time-frame. Interestingly, real imports are the most significant of the domestic variables (even including the own contribution) contributing 21% on average over 12 quarters. This suggests that import prices are a significant component of Korean price level inflation, a phenomenon which is likely to complicate the task of domestic macroeconomic management considerably. Interestingly, however, the contribution of the oil price is negligible at all horizons. This suggests that government intervention in the energy markets seems to have successfully limited the degree to which fluctuations in energy prices are passed through to the Korean economy. Finally, the non-oil foreign contribution is large, rising from 31% to 53% over the twelve quarter horizon. The most important foreign variables on average over 12 quarters are US equity prices, US output, Chinese inflation, the US price level, and European equity prices.

Turning to real output in Panel (g), we once again observe the familiar decline in the own contribution as the horizon rises. The contribution of the other domestic variables remains fairly constant between 13% and 24% across all horizons. As with the case of equity FEVs reported in panel (e), and for the same reasons, the contribution of oil price is considerable from the outset and grows substantially as the horizon increases, reaching 42.5% after 12 quarters. Finally, the non-oil foreign contribution is non-negligible, growing from 16% to 29% over 12 quarters, with the most important variables being the US price level, equity price and real imports. As before, this reflects the dominant position of the US among Korea's trading partners.[8]

Finally, Table 4 provides a crude summary of the key factors influencing various aspects of the Korean economy. Specifically, the table reports the three variables that account for the largest proportion of the FEV for each of the Korean domestic variables separately. As expected, the principle factors affecting the Korean economy are domestic conditions within Korea as well as financial conditions in the US and the European real exchange rate. When broadening the analysis to consider the top ten contributors rather than the top 3 (results are not reported here but full details are available on request) we find that they typically account for between 70% and 90% of the total FEV and that the most heavily represented nations are Korea, the US, the Eurozone, China and Japan, as expected. This seems intuitively plausible, and underscores our earlier contention that the results based on the block diagonal covariance matrix are preferable to those obtained under the unrestricted (non-diagonal) covariance matrix, where a far more diverse group of countries are represented.

[Insert Table 4 about here]

[8] The oil price impacts on growth and inflation will differ across different countries, depending upon their level of exposure and the market deepening. Given that the oil price hikes do not seem to fuel domestic inflation in Korea, especially over the longer horizons as discussed in Subsection 4.1, however, it is worth further investigating the channel through which oil prices impact output and equity prices in Korea.

6 Concluding Remarks

This paper has analysed the international linkages of the Korean macroeconomy within a global framework using the GVAR model developed by GNS. The GNS model considers the same group of 33 countries (26 regions) considered by DdPS but extends their analysis by incorporating trade variables and explicitly modelling intertemporal structural instability by the inclusion of country-specific intercept shift dummies. Accounting for structural instability in this way is vital when studying countries affected by significant and long-lasting economic perturbations such as the 1997 Asian currency crisis. In this sense, the GNS model is therefore ideally suited to our application. Furthermore, it follows that any analysis of regional and global linkages will benefit from being situated within a truly global framework such as the GNS GVAR model. Indeed, given its ability to explicitly model the nature of foreign influences on a sovereign state or economic block, the GVAR framework represent a singularly powerful tool for the analysis of bilateral and multilateral economic interconnections.

In the first stage of our analysis, we considered a selection of GIRFs representing the expected effect of a variety of economically interesting shocks on the Korean economy. Focusing on a small number of GIRFs with respect to an oil price shock, a US interest rate shock, a US stock market shock, a Chinese inflationary shock and a domestic interest rate shock, our results reveal a number of interesting phenomena. Firstly, our results indicate that there is a schism between the sensitivity of the real and nominal sides of the Korean economy in relation to oil prices, with real variables generally responding much more strongly. We attribute this finding to government intervention in the energy markets in the earlier years of our sample. Secondly, we find little evidence that interest rate hikes (whether domestic or foreign) exert significant disinflationary or contractionary effects on the Korean economy; rather, we find evidence to the contrary. In particular, we find that the common dictum that equity prices respond inversely to interest rates does not seem to hold in Korea. Thirdly, we find that the performance of the real economy and the stock market is strongly influenced by the performance of the US economy, and also to a lesser degree by the European, Chinese and Japanese economies. We conclude that these strong linkages will complicate the task of domestic economic management faced by the central bank and the government.

In the second stage of our analysis, we analyse the main contributors to the nomralized generalized forecast error variance of the Korean domestic variables in our global system. Importantly, we find it necessary to impose block-diagonality of the global covariance matrix to refine our analysis and to filter out the distortions arising from imprecise estimation of some of the non-diagonal blocks under free estimation. We employ a simple aggregation of the GFEVDs which yields an estimate of a variable's own contribution to its variance share, the contribution of the other domestic variables, the contribution of the oil price and the contribution of the non-oil foreign variables. Our analysis reveals a number of stylised findings. Firstly, the own contribution dominates over a short horizon after which the foreign variables (including oil) typically becomes the dominant force. Secondly, we find that the interest rate is relatively insensitive to conditions overseas except to the extent that it is significantly effected by the real exchange rate of the Korean Won. Thirdly, the oil price exerts a powerful influence on real exports, equity prices and real output, but not generally in the remaining cases. At an over-arching level, our results suggest that the major sources of overseas influence on the Korean economy are the core macroeconomic variables for the US, the equity indices in the US, the Eurozone and Japan, and the macroeconomic variables for China, most notably inflation. This array of linkages further strengthens our earlier conclusion about the difficulty of successful domestic economic management in Korea.

7 Data Appendix

Variables used in this paper include y ($ln(Y_{it}/CPI_{it})$, real GDP), p ($ln(CPI_{it})$, consumer price index), q ($ln(Q_{it}/CPI_{it})$, real equity price index), e ($ln(E_{it})$, nominal exchange rate in terms of the US Dollar), r ($(0.25 \times ln(1 + R_{it}/100))$, short–term interest rate), x ($ln(\frac{EXPORT_{it} \times E_{it}}{CPI_{it}})$, real exports), m ($ln(\frac{IMPORT_{it} \times E_{it}}{CPI_{it}})$, real imports) and p^o ($ln(POIL_{it})$, nominal spot oil price).

GDP: Nominal GDP series for 33 countries are taken from the International Monetary Fund (IMF)F's International Financial Statistics (IFS), Series 90BVRZF (Index, 2000 = 100). Where quarterly data were not available, quarterly series were generated from annual series using the interpolation procedure of DdPS (see their Supplement A for details of the interpolation procedure). Specifically, the interpolated series were used throughout the sample period for China and Saudi Arabia and during the following sub-periods: 1980-1989 for Argentina, 1980-1990 for Brazil, 1980-1996 for India, 1980-1982 for Indonesia, 1980-1987 for Malaysia, 1980-1989 for Philippines, 1980-1992 for Thailand, 1980-1986 for Turkey. In these countries, quarterly data were available for the remainder of the sample period. Where data were not available, the IFS series were completed by data from other sources: Datastream, OECD, or extrapolated growth rates (using the average growth rate of three previous years). The series for Singapore were completed by Datastream data, while the series for Brazil, India and the UK were completed using OECD data. The series for Argentina, Austria, Belgium, Brazil, Chile, Finland, India, Indonesia, Korea, Malaysia, Mexico, Norway, Peru, Philippines, Sweden, Thailand, and Turkey were seasonally adjusted using the US Census Bureau's X12 routine.

The Consumer Price Index: For most of the 33 countries, the data were taken from IFS Series 64.ZF (Index, 2005 = 100), except for China, Finland and Germany. The series for China (seasonally adjusted from 1987Q1–2007Q2) and Germany (1980Q1–2007Q2) were provided by the Bank of Korea. The series for China was completed by IFS Series 64.XZF. Meanwhile, Finland's price index was collected from IFS Series 63EY.ZF.

Nominal Exchange Rate: IFS Series RF.ZF (national currency per US$) were used for all countries. The Eurozone's nominal exchange rate was constructed from the series of 8 member countries (Austria, Belgium, France, Finland, Germany, Italy, Spain, and Netherlands) during the period of 1980–1998 and the Euro/US$ exchange rate was used from 1999 onwards.

Short–term Interest Rate: The data (measured in percent per annum) were taken from IFS Series 60B..ZF (money market – interbank – rate) for 16 countries. The data for Argentina, Chile, China and Turkey were taken from IFS Series 60L..ZF (deposit rate). For Sweden, IFS

Series 60B..ZF was completed by IFS Series 60A..ZF from 2004Q4. For Mexico, IFS Series 60C..ZF (Treasury bill rate) was used while IFS Series 60..ZF (discount rate) were used for New Zealand and Peru. For India, the data covering the period of 1998Q2–2006Q2 were retrieved from the Reserve Bank of India. No reliable short–term interest rate is published by the Saudi Arabian Monetary Agency. For Norway, the NIBOR 3–month rates from the OECD was used. For the Eurozone countries, Finland, Germany, Italy and Spain had their own short–term interest rate series over the full sample period while the series for the 4 remaining countries (Austria, Belgium, France, and Netherlands) ended at 1998Q4. For these latter countries, their interest rate series were completed by the Euro interbank rate.

Exports and Imports: The data for exports and imports (measured in millions US$) of 33 countries were from IFS Series 70..DZF (for exports) and IFS Series 71..DZF (for imports). Where necessary , the data were extrapolated backward using and export and import growth rates obtained from the World Bank data. This technique was applied for China's export and import in 1980 and for Belgium's export and import over 1980–1992. The quarterly series for Saudi Arabia were interpolated from the annual series. All the series were seasonally adjusted using the US Census Bureau's X12 routine.

Equity Price Index: The data were collected from IFS Series 62..ZF (industrial share prices index) for 26 countries. The IFS series of Argentina, Singapore and Thailand were completed using data from Datastream. The data for the UK, Switzerland and Mexico were collected from the OECD's Main Economic Indicators. Reliable equity price index data for China, Indonesia, Peru, Turkey and Saudi Arabia were unavailable.

Oil Price: The UK Brent series (US$ per barrel) from IFS Commodity Price was used.

References

Adolfson, M., Lindé, J. and Villani, M. (2007) "Forecasting Performance of an Open Economy DSGE Model," *Econometric Reviews*, 26(2), 289-328. 1

Bank of England (2008) "Inflation Report: February 2008," London: Bank of England.

Barro, R.J. and Sala-i-Martin, X. (1997) "Technological Diffusion, Convergence, and Growth," *Journal of Economic Growth*, 2, 1-26.

Bayoumi, T. (2004) "GEM: A New International Macroeconomic Model," Occasional Paper No. 239, Washington D.C.: International Monetary Fund. 2

Botman, D., Karam, P., Laxton, D. and Rose, D. (2007) "DSGE Modeling at the Fund: Applications and Further Developments," Working Paper No. 07/200, Washington D.C.: International Moneon block-diagonal covarianctary Fund. 2

Bussière, M., Chudik, A. and Sestieri, G. (2009) "Modelling Global Trade Flows: Results from a GVAR model," Working Paper No. 1087, Frankfurt: European Central Bank. 1

Casillas-Olvera, G. and Bessler, D. (2006) "Probability Forecasting and Central Bank Accountability," *Journal of Policy Modeling*, 28(2), 223-234.

Chen, Q., Gray, D., N'Diaye, P., Oura, H. and Tamirisa, N. (2009) "International Transmission of Bank and Corporate Distress," Working Paper No. WP/10/124, Washington D.C.: International Monetary Fund. 1

Cristadoro, R., Gerali, A., Neri, S. and Pisani, M. (2006) "Nominal Rigidities in an Estimated Two Country DSGE Model." Paper presented at the 12^{th} International Conference on Computing in Economics and Finance, Limassol (Cyprus), June 22-24, 2006. 2

Dees, S., di Mauro, F., Pesaran, M.H. and Smith, L.V. (2007) "Exploring the International Linkages of the Euro Area: A Global VAR Analysis," *Journal of Applied Econometrics*, 22, 1-38. 1

Dees, S. Holly, S., Pesaran, M.H. and Smith, L.V. (2007) "Long Run Macroeconomic Relations in the Global Economy," *Economics*, 3, 1-56. 1

Del Negro, M. and Schorfheide, F. (2004) "Priors from General Equilibrium Models for VARs," *International Economic Review*, 45(2), 643-3. 2

de Walque, G., Smets, F. and Wouters, R. (2005) "An Estimated Two-Country DSGE Model for the Euro Area and the US Economy," Paper presented at the 21^{st} Annual European Meeting of the Econometric Society, Vienna, August 27, 2006. 2

Diebold, F.X. and Yilmaz, K. (2009) "Measuring Financial Asset Return and Volatility Spillovers, with Application to Global Equity Markets," *Economic Journal*, 119, 158-171. 2.4

Diebold, F.X. and Yilmaz, K. (2011) "On the Network Topology of Variance Decompositions: Measuring the Connectedness of Financial Firms," Working Paper No. 17490, Cambridge (MA): National Bureau of Economic Research. 2.4

Dornbusch, R. (1976) "Expectations and Exchange Rate Dynamics," *Journal of Political Economy*, 84, 1161-1176. 4.5

Ericsson, N.R. (2001) "Forecast Uncertainty in Economic Modeling," International Finance Discussion Paper No. 697, Washington D.C.: Board of Governors of the Federal Reserve System.

Garratt, A., Lee, K, Pesaran, M.H. and Shin, Y. (2006) *Global and National Macroeconometric Modelling: A Long-Run Structural Approach*. Oxford: Oxford University Press.

Giordani, P. and Söderlind, P. (2003) "Inflation Forecast Uncertainty," *European Economic Review*, 47(6), 1037-1059.

Greenspan, A. (1996) "The Challenge of Central Banking in a Democratic Society." Remarks at the Annual Dinner and Francis Boyer Lecture of the American Enterprise Institute for Public Policy Research, Washington D.C., December 5, 1996.

Greenwood-Nimmo, M.J., Nguyen, V.H. and Shin, Y. (2012a) "Probabilistic Forecasting of Output Growth, Inflation and the Balance of Trade in a GVAR Framework," *Journal of Applied Econometrics*, 27(4), 554-573. (document), 1

Greenwood-Nimmo, M.J., Nguyen, V.H. and Shin, Y. (2012b) Using Global VAR Models for Scenario-Based Forecasting and Policy Analysis. In F. di Mauro and M.H. Pesaran (Eds.) "*The GVAR Handbook: Structure and Applications of a Macro Model of the Global Economy for Policy Analysis*," (Chapter 7). Oxford: OUP. Forthcoming. 1

Officer, L.H. (1976) "The Productivity Bias in Purchasing Power Parity: An Econometric Investigation," *IMF Staff Papers*, 23, 545-579.

Pagan, A. (2003) "Report on Modelling and Forecasting at the Bank of England," *Bank of England Quarterly Bulletin*, 43(1), 1-29. 2

Pesaran, M.H., Schuermann, T. and Smith, L.V. (2009) "Forecasting Economic and Financial Variables with Global VARs," *International Journal of Forecasting*, 25(4), 642-675.

Pesaran, M.H., Schuermann, T. and Weiner, S.M. (2004) "Modeling Regional Interdependencies Using a Global Error-Correcting Macroeconometric Model," *Journal of Business and Economic Statistics*, 22, 129-162. 1

Pesaran, M.H. and Shin, Y. (2002) "Long-Run Structural Modelling," *Econometric Reviews*, 21, 49-87. 2.1

Pesaran, M.H., Shin Y. and Smith, R.J. (2000) "Structural Analysis of Vector Error Correction Models with Exogenous I(1) Variables," *Journal of Econometrics*, 97, 293-343.

Sgherri, S. and Galesi, A. (2009) "Regional Financial Spillovers Across Europe: A Global VAR Analysis," Working Paper No. 09/23, Washington D.C.: International Monetary Fund. 1

Shin, Y. (2009) "The Cointegrating VAR Modelling Approach to the Korean Macroeconomy in the Presence of Structural Breaks," *The Korean Journal of Economics*, 16: 175-241. 1, 2.1, 4, 4.1, 4.2, 4.5

Sims, C. (1980) "Macroeconomics and Reality," *Econometrica*, 48, 1-48. 2

Smets, F. and Wouters, R. (2007) "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," *American Economic Review*, 97(3), 586-606. 1

Order	Country	Code	r	n	k	Official Inflation Target	Probable Cause of Break
0	USA	USA	3	7	3	None	
1	Eurozone*	EUR	3	7	5	HICP <2% & ≈2%	Introduction of the Euro (1999Q1)
2	Japan	JAP	6	7	5	None	The real-estate/stock market crash (1992Q1)
3	UK	UK	3	7	5	2% CPI ±1%	Departure from the ERM (1992Q4)
4	Norway	NOR	3	7	5	2.5% CPI	
5	Sweden	SWE	4	7	5	2% CPI ±1%	
6	Switzerland	SWI	5	7	5	<2% CPI	
7	Canada	CAN	3	7	5	2% CPI ±1%	
8	Australia	AUS	3	7	5	2-3% CPI	
9	New Zealand	NZ	3	7	5	1-3% CPI	
10	South Africa	SAF	3	7	5	3-6% CPIX	
11	Argentina	ARG	5	7	5	None	Effects of the Convertibility Plan (1991Q4)
12	Brazil	BRA	3	7	5	4.5% CPI ± 2%	Effects of the Real Plan (1994Q4)
13	Chile	CHL	4	7	5	3% CPI ±1%	
14	Mexico	MEX	4	7	5	3% CPI	Mexican Peso Crisis (1995Q2)
15	India	IND	3	7	5	None	
16	Korea	KOR	4	7	5	3% CPI ± of 0.5%	S.E. Asian crisis (1997Q4)
17	Malaysia	MAL	5	7	5	None	S.E. Asian crisis (1997Q3)
18	Philippines	PHI	3	7	5	4-5% CPI	S.E. Asian crisis (1997Q4)
19	Singapore	SNG	4	7	5	None	
20	Thailand	THA	4	7	5	0-3.5% CPIX	S.E. Asian crisis (1997Q3)
21	China	CHN	3	6	5	None	
22	Indonesia	INS	4	6	5	5% CPI ± 1%	S.E. Asian crisis (1997Q3)
23	Peru	PER	4	6	5	1-3% CPI	Dollarisation 'Washington consensus' (1994Q3)
24	Turkey	TUR	2	6	5	5% CPI	
25	Saudi Arabia	SAR	4	5	5	None	

Note: r , n and k are the numbers of cointegrating vectors, endogenous variables and exogenous variables for each country/region, respectively. (.) is our chosen break point. * For our purposes, the Eurozone includes Austria, Belgium, Finland, France, Germany, Italy, the Netherlands and Spain only. Eurozone data are constructed by aggregating the contributions of these member states using a PPP-GDP weighting scheme. The only exceptions are Eurozone's export and import series which are the total of member states exports and imports, respectively.

Table 1: Details of Country-Specific Models in the GVAR Framework

	Inflation				Output Growth			
	Mean	St. dev.	Max	Min	Mean	St. dev.	Max	Min
US	3.45	2.28	11.3	-3.42	3.05	2.68	8.92	-6.61
EU	3.41	2.36	11.8	0.02	2.17	2.25	14.3	-2.84
JAP	0.99	2.53	9.42	-4.0	2.58	3.75	12.4	-7.51
UK	4.18	3.66	19.2	-2.68	2.57	2.25	8.81	-4.64
NOR	4.05	3.93	18.5	-6.70	2.85	7.24	26.8	-12.9
SWE	4.01	4.29	18.6	-3.82	2.41	4.53	15.0	-8.51
SWI	2.20	2.65	9.56	-2.61	1.71	2.16	7.61	-2.87
CAN	3.51	3.14	12.8	-3.67	2.76	3.01	9.87	-6.08
AUS	4.48	3.68	16.3	-1.67	3.26	3.17	11.6	-6.09
NZ	5.08	5.65	34.2	-3.18	3.21	8.68	41.3	-31.8
SAF	9.41	5.56	22.9	-8.33	2.29	3.39	10.0	-8.55
ARG	70.2	118.8	759.2	-4.20	1.95	9.23	21.3	-25.4
BRA	97.4	120.8	622.6	-1.41	2.55	7.00	19.2	-29.0
CHL	11.0	9.80	46.2	-1.42	4.49	8.31	33.2	-25.8
MEX	26.1	26.7	131.4	-0.43	2.64	6.26	15.1	-24.7
IND	7.54	6.76	24.2	-16.0	5.97	6.09	28.4	-12.9
KOR	4.95	4.92	28.7	-2.72	6.43	6.80	26.2	-34.3
MAL	3.02	2.78	14.9	-2.43	5.95	6.14	19.9	-26.8
PHI	8.94	10.1	63.6	-14.0	2.99	6.08	18.0	-25.0
SIN	1.67	2.64	13.7	-4.63	6.76	6.42	26.9	-13.8
THA	3.89	3.59	15.8	-4.98	5.69	6.28	25.2	-20.5
CHN	5.37	7.08	33.9	-2.87	9.48	3.16	17.3	0.69
INDO	10.03	12.0	73.1	-9.08	4.68	9.46	48.6	-37.3
PER	66.93	121.8	856.53	-2.38	2.39	12.9	28.0	-55.0
TUR	40.10	22.6	136.1	3.07	4.41	9.98	25.6	-46.2
SAU	0.51	3.57	17.6	-18.4	1.66	9.01	20.1	-23.0

Table 2: Historical Inflation and Output Growth by Country/Region (% per annum)

	Import Growth				Export Growth				Current
	Mean	St. dev.	Max	Min	Mean	St. dev.	Max	Min	Account
US	4.11	12.2	50.1	-36.2	2.62	11.6	27.6	-29.3	-1.49
EU	2.88	12.2	31.8	-25.8	3.38	11.3	33.2	-20.7	0.50
JAP	1.88	21.0	48.1	-60.9	2.86	15.6	40.2	-49.9	0.98
UK	2.39	16.2	65.9	-49.4	1.30	18.6	38.1	-86.8	-1.09
NOR	2.22	21.0	53.7	-44.7	3.89	25.8	59.8	-93.7	1.66
SWE	3.21	16.4	46.0	-57.9	4.26	17.3	66.40	-35.5	1.05
SWI	1.82	16.2	80.2	-36.7	2.79	13.5	34.50	-30.7	0.96
CAN	3.00	18.1	64.8	-50.1	3.20	18.3	99.3	-48.6	0.20
AUS	4.17	17.1	38.9	-72.5	3.49	20.8	80.8	-50.7	-0.68
NZ	2.37	28.6	82.5	-80.2	1.56	20.8	55.5	-52.6	-0.80
SAF	4.26	32.5	83.5	-106.4	2.64	29.7	61.3	-85.2	-1.62
ARG	5.51	61.6	338.2	-178.5	7.44	69.4	391.4	-166.6	1.93
BRA	2.38	37.6	103.7	-85.4	4.27	49.6	191.2	-174.5	1.89
CHL	6.01	27.6	57.4	-92.1	8.58	31.8	114.1	-93.1	2.57
MEX	6.63	30.0	119.8	-175.9	6.84	44.5	229.1	-139.6	0.20
IND	8.56	30.2	88.4	-127.6	9.02	23.9	78.8	-58.9	0.46
KOR	6.97	22.5	87.3	-65.5	8.18	27.2	120.9	-67.9	1.20
MAL	8.34	22.3	63.2	-65.1	8.04	21.0	71.1	-64.1	-0.30
PHI	4.92	34.3	76.7	-137.7	5.85	51.4	305.3	-150.7	0.93
SIN	5.87	17.5	40.5	-41.4	7.13	17.8	65.6	-34.6	1.26
THA	8.23	25.7	79.6	-92.8	10.0	24.0	87.2	-92.8	1.78
CHN	14.0	35.4	149.7	-139.9	16.1	24.9	119.0	-43.1	2.11
INDO	8.05	53.4	163.8	-226.5	5.70	52.5	255.4	-258.0	-2.35
PER	1.14	46.3	137.1	-168.9	0.63	52.4	218.3	-153.7	-0.51
TUR	7.78	34.5	137.9	-78.2	9.70	38.9	129.1	-119.4	1.91
SAU	3.88	18.9	35.7	-47.3	2.96	36.0	83.8	-67.1	-0.93

Table 3: Historical Imports and Exports Growth and Current Account Position by Country/Region (% per annum)

Horizon	re	r	im	ex	q	π	y
$h=1$	KOR re (22%) JAP re (14%) EU re (10%)	KOR r (67%) US y (4%) BRA r (3%)	KOR im (62%) KOR ex (12%) KOR y (9%)	KOR ex (59%) KOR re (13%) KOR im (12%)	KOR q (58%) US q (16%) po (6%)	KOR im (5%) KOR dp (61%) US q (8%)	KOR y (68%) KOR im (9%) US q (7%)
$h=4$	EU re (20%) KOR re (16%) KOR q (15%)	KOR r (20%) KOR re (19%) KOR q (12%)	KOR im (28%) US q (15%) KOR dp (9%)	KOR re (14%) KOR ex (16%) US q (13%)	KOR q (31%) po (21%) US q (13%)	KOR im (21%) KOR dp (17%) US q (12%)	po (28%) KOR y (26%) US p (11%)
$h=8$	EU re (21%) KOR q (15%) KOR re (12%)	KOR re (20%) KOR q (19%) US q (13%)	KOR im (24%) US q (21%) KOR dp (10%)	po (19%) US q (13%) US p (10%)	po (30%) KOR q (23%) US p (12%)	KOR im (23%) KOR dp (17%) US q (16%)	po (39%) KOR y (15%) US p (11%)
$h=12$	EU re (20%) KOR q (14%) KOR re (11%)	KOR re (20%) KOR q (20%) US q (14%)	KOR im (24%) US q (19%) KOR dp (10%)	po (18%) KOR re (8%) US q (8%)	po (34%) KOR q (21%) US p (11%)	KOR im (25%) KOR dp (16%) US q (16%)	po (43%) KOR y (13%) US p (10%)
Average	EU re (20%) KOR re (15%) KOR q (13%)	KOR r (20%) KOR re (17%) KOR q (14%)	KOR im (29%) US q (16%) KOR dp (9%)	KOR ex (14%) po (13%) KOR re (13%)	KOR q (30%) po (25%) US q (12%)	KOR im (21%) KOR dp (20%) US q (14%)	po (32%) KOR y (24%) US p (10%)

Table 4: Main Contributors to GFEVDs of Korean Variables

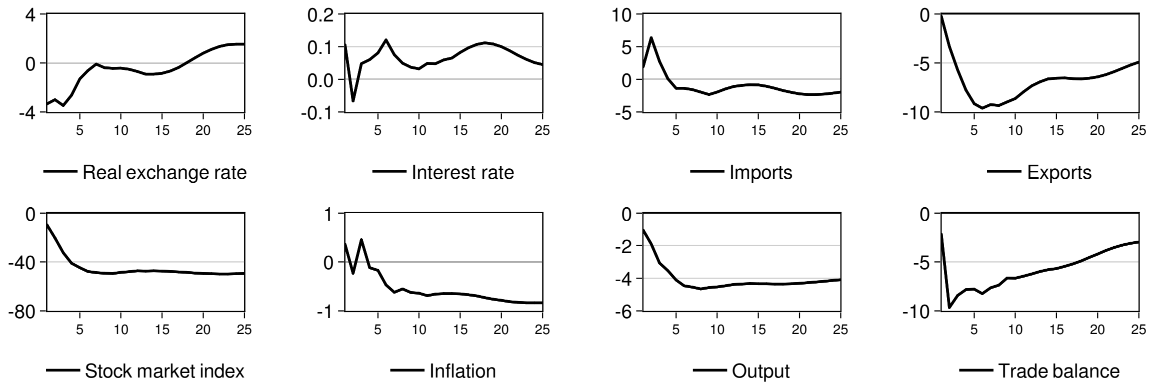


Figure 1: GIRFs w.r.t. a Positive Oil Price Shock

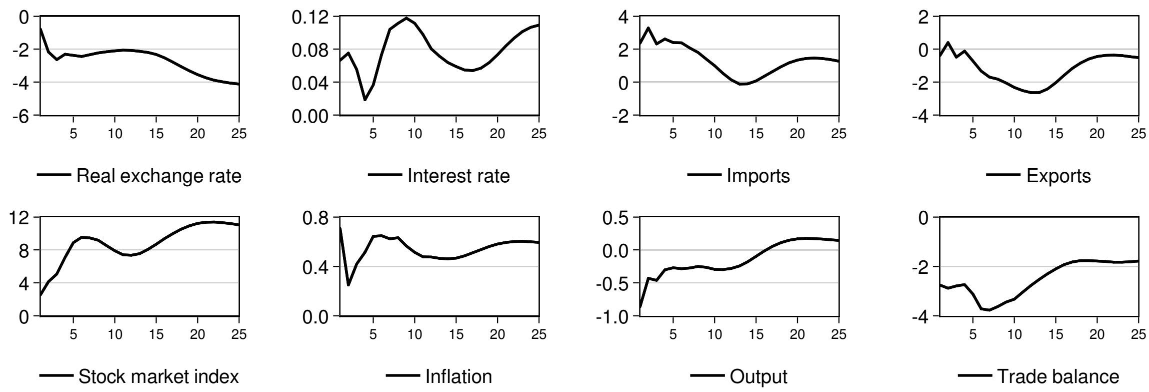


Figure 2: GIRFs w.r.t. a Positive US Interest Rate Shock

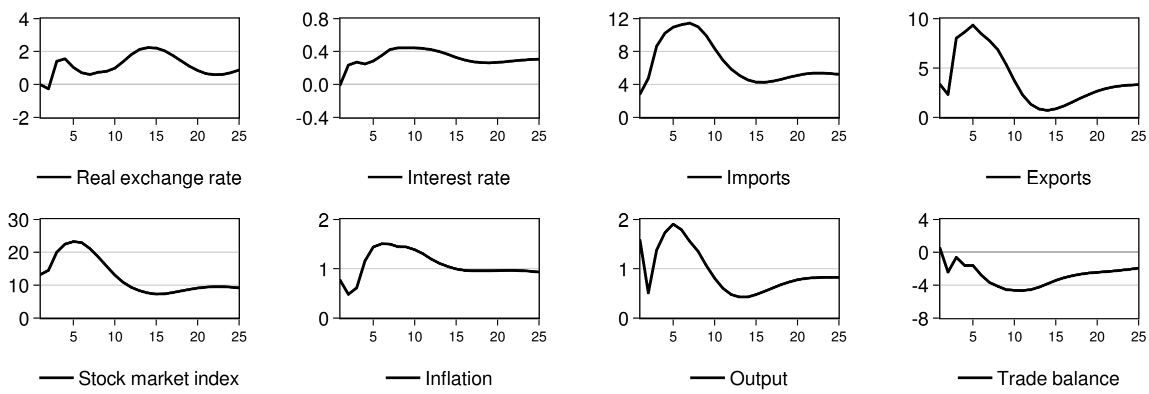


Figure 3: GIRFs w.r.t. a Positive US Stock Market Shock

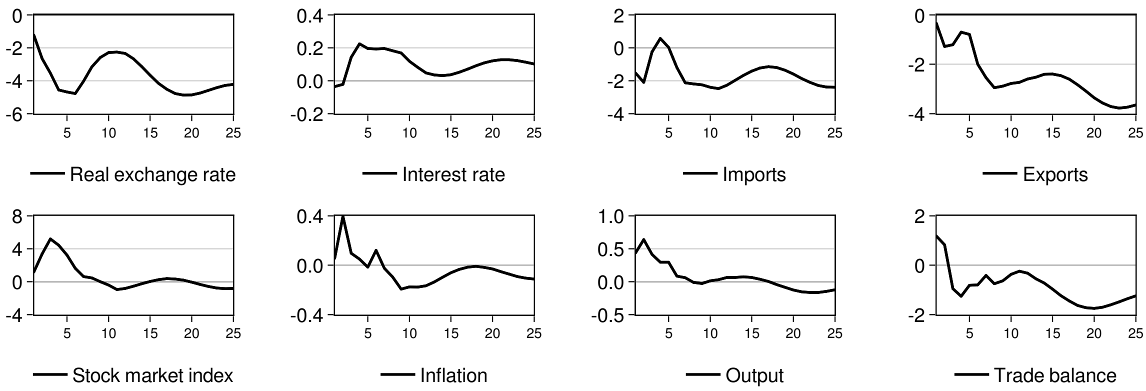


Figure 4: GIRFs w.r.t. a Positive Chinese Inflation Shock

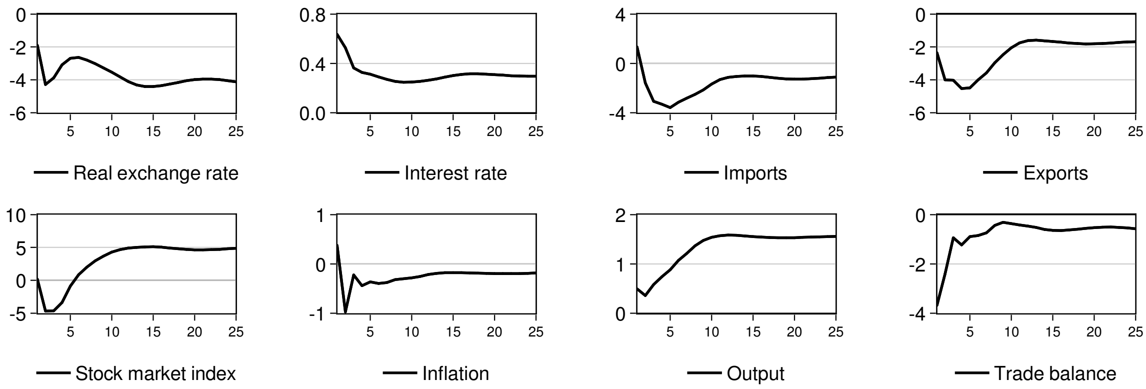
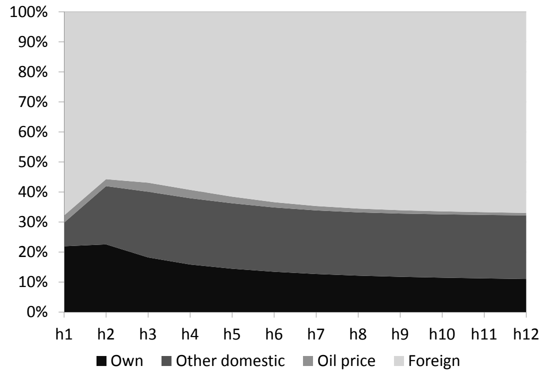
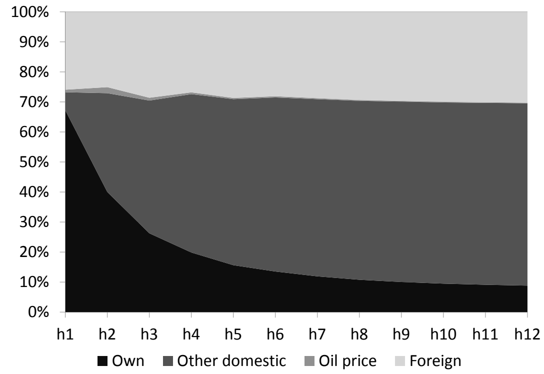


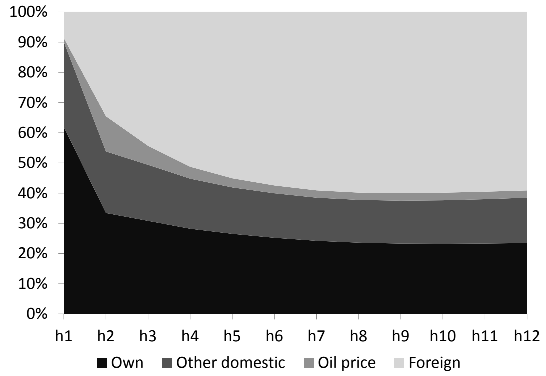
Figure 5: GIRFs w.r.t. a Positive Korean Interest Rate Shock



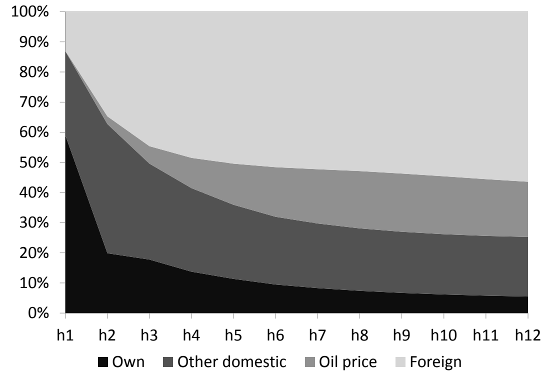
(a) Real exchange rate



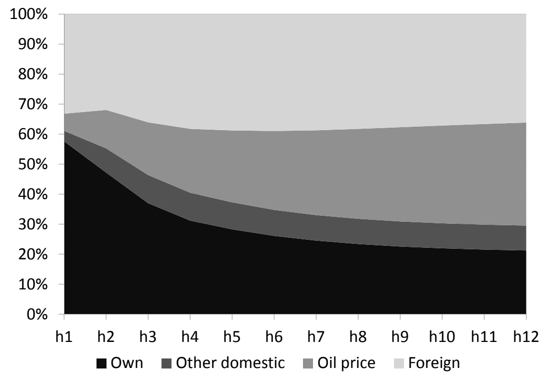
(b) Interest rate



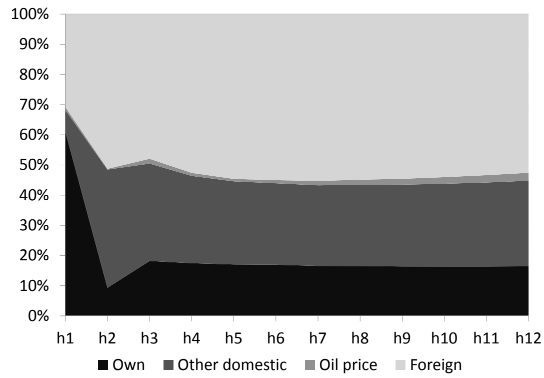
(c) Imports



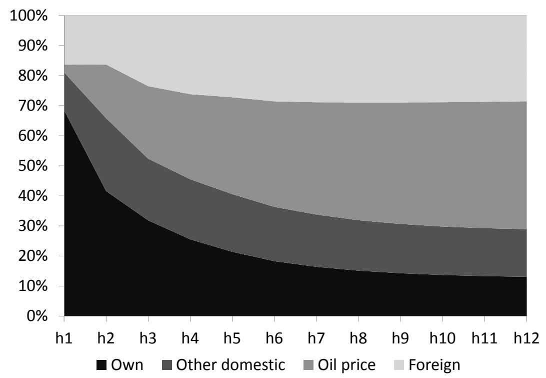
(d) Exports



(e) Stock market index



(f) Inflation



(g) Output

Figure 6: GFEVDs of Korean variable at $h = 1, ..., 12$.