

# International Economic Linkages between Taiwan and the World: A Global Vector Autoregressive Approach

**Shu-Ling Chen**

Department of Quantitative Finance  
National Tsing Hua University

**Chao-Hsi Huang**

Department of Economics  
National Tsing Hua University

**Yu-Lieh Huang**

Department of Quantitative Finance  
National Tsing Hua University

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Author for correspondence: Yu-Lieh Huang, Department of Quantitative Finance, National Tsing Hua University, 101, Sec. 2, Kuang-Fu Road, Hsinchu 30013, Taiwan; ylihuang@mx.nthu.edu.tw; phone: +886 3 516-2125.

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## Abstract

This paper applies the global vector autoregressive (GVAR) model proposed by Pesaran et al. (2004) and Dees et al. (2007) to analyze how a shock to the macroeconomies of Taiwan's major trading partners (such as U.S. and China) influence the economies of Taiwan and the rest of the world. Our results indicate that the performance of the GVAR model is rather encouraging, in the sense that the effects of macroeconomic shocks are generally consistent with our expectations based on macroeconomic theory. In contrast to the existing literature on the Taiwanese macroeconomy, our paper evaluates the impacts of shocks on Taiwan's macroeconomy from a global perspective.

**Keywords:** global vector autoregressive model, GVAR model, international linkage, macroeconomy, Taiwan

**JEL Classification:** C10, C22, C52, E50, E52

# 1 Introduction

The term of “globalization” has been used extensively by media, economists, and policymakers over the last two decades to indicate increasing integration and interdependence in the world economy as a result of expanding trade, production sharing, investment, and other service outsourcing. International cooperation and free trade initiatives may have also bolstered the globalization process. These are exemplified by the establishment of international free trade initiatives, such as the World Trade Organization (WTO), or regional cooperation, such as European Union (EU) and the Association of Southeast Asian Nations (ASEAN), and various regional trade agreements (RTAs), e.g., free trade agreements (FTAs), customs unions and common markets. Because of the rapid increase in globalization, there is a growing desire to model the intricate interrelationships that exist among national economies, and to understand how economic conditions in one country may directly or indirectly influence the economic conditions in other countries.

Over the years, many macroeconomists and econometricians have attempted to develop large-scale macroeconomic models to forecast and to quantify the global economic consequences of policies adopted by different countries. A prominent example is “Project LINK”, which was initiated by Lawrence Klein in the late 60s. This project integrates the large-scale structural macroeconomic models of different countries in a global framework, with the objective of improving our understanding of international economic linkages and forecasting international trade and capital movements. Other existing macroeconomic global models, including the NIESR (National Institute for Economic and Social Research) global model, the NiGEM (National Institute Global Econometric Model) and the Federal Reserve Board global model, are also widely used by the government policy community and private commercial sectors. However, the details of these models are usually unavailable and cannot be properly evaluated by others, cf. Granger and Jeon (2007).

In recent years, Pesaran et al. (2004), Dees et al. (2007) and Dees et al. (2008) have developed a practical method for evaluating global macroeconomic linkages through employing country-specific vector autoregressive (VAR) models. Specifically, the global VAR (hereafter GVAR) model is constructed using country- or regional-specific vec-

tor error correction models in which all variables in the domestic and foreign countries/regions can interact simultaneously. The GVAR model accounts for a large number of international interrelationships across macroeconomic and financial variables in different countries around the globe. The model allows us to evaluate how a shock to a macroeconomic variable in a given country may affect the macroeconomic variables of other countries using impulse response analysis.

In this paper, our primary objective is to apply the GVAR model developed by Pesaran et al. (2004) and Dees et al. (2007) to analyze international economic linkages between Taiwan and the rest of the world. Taiwan is a small export-oriented economy that is highly dependent on global trade, making it highly vulnerable to downturns in the world economy, especially to shocks originating from its major trading partners. It is therefore of special interest to Taiwanese macroeconomists and policy authorities to understand how monetary policies in Taiwan's major trading partners influence the Taiwanese macroeconomy as well as those for the rest of the world. Here, by accounting for Taiwan's economic conditions as well as the economic conditions in other countries, our model allows us to evaluate how a monetary and financial shock in one of Taiwan's major trading partners (such as U.S. and China) affect Taiwan. Specifically, we focus our analysis on impulse responses generated by six different shocks, including an oil price shock, a U.S. real output shock, a U.S. equity price shock, a U.S. interest rate shock, a China real output shock and a Taiwan real output shock, and assess the effect of every shock on macroeconomic activities in Taiwan and the rest of the world.

The results obtained using a GVAR model are encouraging, in the sense that the effects of macroeconomic shocks are generally consistent with our expectations and with the existing theoretical literature. We find that, in the short term: (i) an increase in the price of oil leads to a significantly increase in the inflation rates in most countries, including Taiwan. The effect of an increase in oil price on Taiwan's real output is also significant; (ii) a decline in U.S. real output reduces real GDP and employment in Taiwan and the rest of the world; (iii) a decline in U.S. equity prices causes a decline in equity prices in Taiwan and the rest of the world. However, we found that such negative U.S. equity price shock does not affect the real output in many countries but the four Asian Tigers (i.e., Taiwan, Hong Kong, Korea and Singapore); (iv) a tight monetary policy in the U.S. will increase inflation rates, which is so called "price puzzle" in the

macroeconomic literature. However, such price puzzle is insignificant and will quickly fade away; (v) a decline in China real output does not have significant impacts on the macroeconomic factors in most selected countries around the world, which may be attributed to the fact that China has just enjoyed his fast growth in the very recent years. Therefore, the impact of China real output shock on the world may not be as significant as U.S. does; and (vi) a negative shock to Taiwan's real output results in the reduction of interest rate and real equity price in Taiwan and an increase in unemployment rate.

In contrast to the existing macroeconometric literature, the contributions of this paper are twofold. First, to our knowledge, this paper is the first attempt applying the GVAR model to the study of interrelationship between the economy of Taiwan and those of its major trading partners. Due to the complicated nature of the intertwining relation between the economies studied, we believe that the GVAR model, a model specifically designed to study such problem, should provide more accurate and insightful descriptions on such relations. Second, apart from previous studies which mainly focus on exploring the implications of Taiwan macro policies on domestic activities, e.g., Lin (2010), Pang and Chou (2001), and Wu et al. (2002), in this paper we not only considered economic activities and financial market in Taiwan but also allowed for the interdependences that exist between national and international macroeconomic factors by applying GVAR model of Dees et al. (2007). In particular, we expanded the GVAR model of Dees et al. (2007) by including Taiwan and the other markets (i.e., Hong Kong) in the global model and compare how these economies react to global shocks or the shocks originating from large economies such as the U.S.<sup>1</sup>

The paper is organized as follows: in the next section, we introduce the GVAR model and discuss estimation of and inference with the model. In the subsequent section, we explain the core macroeconomic variables used in the study and carry out the ADF-GLS test of Elliott et al. (1996) to examine whether these variables are integrated of order one. In the following section, we estimate the model and identify the rank of co-integration across countries. In the following section, we perform an impulse response

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<sup>1</sup>Our GVAR models are also estimated using longer sample period than that in Dees et al. (2007). The data employed in this paper is over the period 1981:I–2008:IV, which is considerably longer than the sample period of 1979:I–2003:IV employed in Dees et al. (2007).

analysis with respect to different shocks. In the final section, we conclude this paper.

## 2 GVAR Modelling Approach

Suppose that there are  $N + 1$  countries (or regions) in the global economy indexed by  $i = 0, 1, 2, \dots, N$ . Country 0, the U.S., is regarded as the reference country. For each country  $i$ , an augmented VARX( $\check{p}_i, \check{q}_i$ ) model is assumed:

$$\mathbf{x}_{i,t} = \mathbf{a}_{i,0} + \mathbf{a}_{i,1}t + \sum_{j=1}^{\check{p}_i} \Phi_{i,j} \mathbf{x}_{i,t-j} + \sum_{j=0}^{\check{q}_i} \Psi_{i,j} \mathbf{x}_{i,t-j}^* + \sum_{j=0}^{\check{s}_i} \Gamma_{i,j} \mathbf{d}_{t-j} + \boldsymbol{\varepsilon}_{i,t} \quad (1)$$

for  $t = 1, 2, \dots, T$  and  $i = 0, 1, \dots, N$ , where  $\mathbf{x}_{i,t}$  is an  $m_i \times 1$  vector of country-specific domestic core variables,  $\mathbf{x}_{i,t}^*$  is an  $m_i^* \times 1$  vector of country-specific foreign variables,  $\mathbf{d}_t$  is an  $m_d$ -dimensional vector of observed global exogenous variables, such as oil prices, and  $\boldsymbol{\varepsilon}_{i,t}$  denotes a  $k_i \times 1$  vector of mutually independent shocks specific to country  $i$  with mean  $\mathbf{0}$  and variance-covariance matrix  $\Sigma_{ii}^\varepsilon$ . The dimensions of the coefficients  $\Phi_{i,j}$ ,  $\Psi_{i,j}$  and  $\Gamma_{i,j}$  are  $m_i \times m_i$ ,  $m_i \times m_i^*$  and  $m_i \times m_d$ , respectively. Following Pesaran et al. (2004), foreign variables specific to country  $i$  are the country-specific weighted average of other variables:

$$\mathbf{x}_{i,t}^* = \sum_{j=0}^N w_{i,j} \mathbf{x}_{j,t}, \quad \text{with } w_{ii} = 0 \quad \text{and} \quad \sum_{j=0}^N w_{i,j} = 1, \quad (2)$$

where the weight  $w_{i,j}$  is used to represent international transmission channels. In our empirical application, the weight  $w_{i,j}$  is the share of country  $i$ 's total trade volume with country  $j$  measured in U.S. dollars.<sup>2</sup> The  $N + 1$  country-specific models in equation (1), together with the foreign variables in equation (2) and global exogenous variables  $\mathbf{d}_t$ , provide a complete system for an integrated model at the global level.

There are some novel features in the equations (1) and (2) of the GVAR model. First, the GVAR model allows for global interactions through three distinct, but inter-related channels – namely,

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<sup>2</sup>The weight could also be based on capital flows. However, information on capital flows are not of sufficiently high quality and tend to be rather volatile; see, e.g., Pesaran et al. (2004). We also follow Dees et al. (2007) and use a time-varying weight for our analysis. We find no qualitative differences between these results and those discussed in this paper.

- (i) global interaction from the contemporaneous dependence of  $\mathbf{x}_{i,t}$  on foreign variables  $\mathbf{x}_{i,t}^*$  and its lagged values;
- (ii) global interaction from the dependence of country-specific variables on observed common global effects  $\mathbf{d}_{t-j}$  for  $j = 0, 1, 2, \dots$ ; and
- (iii) channels of transmission from the dependence among shocks  $\text{cov}(\boldsymbol{\varepsilon}_{i,t}, \boldsymbol{\varepsilon}_{j,t}) = \boldsymbol{\Sigma}_{ij}^\varepsilon \neq \mathbf{0}$  for  $i \neq j$ .

Ignoring international linkages in our model may bias estimates of the coefficients. Second, as shown in Garratt et al. (2003), the GVAR model provides a practical approach to incorporating theory-based long-run structural relationships in a small open macroeconomy. Finally, the GVAR model allows for both intra- and inter-country co-integration; see e.g. Pesaran et al. (2004) for more details.

## 2.1 Model Estimation

The global model, i.e., equations (1) and (2), provide a complete system of  $N + 1$  country-specific variables that ideally should be estimated simultaneously. However, as argued by Pesaran et al. (2004), such a system estimation of the global model is not feasible because the number of parameters that need to be estimated exceeds the number of observations available. To circumvent the problem, the two-step estimation procedure suggested by Pesaran et al. (2004) and Dees et al. (2007) is employed here. In the first step, we treat the foreign and observed global variables as weakly exogenous, and equation (1) is then independently estimated on a country-by-country basis. This is a common assumption in the macroeconomic literature (e.g., Fleming, 1962; Dornbusch, 1976) that treats most economies, with the possible exception of the U.S., as small relative to the world economy. In the second step, the estimated coefficients from the country-specific submodels are stacked as one big system. There are several purposes for doing this, including analyzing impulse responses, forecasting variables, and etc.

To give a clear illustration of the estimation procedure, we start the first-step procedure by employing a simple VARX(2,1) model for country  $i$ :

$$\begin{aligned} \mathbf{x}_{i,t} = & \mathbf{a}_{i,0} + \mathbf{a}_{i,1} t + \boldsymbol{\Phi}_{i,1} \mathbf{x}_{i,t-1} + \boldsymbol{\Phi}_{i,2} \mathbf{x}_{i,t-2} \\ & + \boldsymbol{\Psi}_{i,0} \mathbf{x}_{i,t}^* + \boldsymbol{\Psi}_{i,1} \mathbf{x}_{i,t-1}^* + \boldsymbol{\Gamma}_{i,0} \mathbf{d}_t + \boldsymbol{\Gamma}_{i,1} \mathbf{d}_{t-1} + \boldsymbol{\varepsilon}_{i,t}. \end{aligned}$$

This country-specific submodel has the following error-correction representation:

$$\begin{aligned} \Delta \mathbf{x}_{i,t} = & \mathbf{a}_{i,0} + \mathbf{a}_{i,1} t - (\mathbf{A}_i - \mathbf{B}_i) \mathbf{z}_{i,t-1} + (\mathbf{\Gamma}_{i,0} + \mathbf{\Gamma}_{i,1}) \mathbf{d}_{t-1} \\ & - \mathbf{\Phi}_{i,2} \Delta \mathbf{x}_{i,t-1} + \mathbf{\Psi}_{i,0} \Delta \mathbf{x}_{i,t}^* + \mathbf{\Gamma}_{i,0} \Delta \mathbf{d}_t + \varepsilon_{i,t}, \end{aligned} \quad (3)$$

where  $\mathbf{z}_{i,t} = (\mathbf{x}'_{i,t}, \mathbf{x}^*{}'_{i,t})'$ ,  $\mathbf{A}_i = (\mathbf{I}, -\mathbf{\Psi}_{i,0})$  and  $\mathbf{B}_i = (\mathbf{\Phi}_{i,1} + \mathbf{\Phi}_{i,2}, \mathbf{\Psi}_{i,1})$ . The error-correction properties of the submodel for country  $i$  are summarized in the  $m_i \times (m_i + m_i^*)$  matrix of  $(\mathbf{A}_i - \mathbf{B}_i)$ . In particular, the rank of  $(\mathbf{A}_i - \mathbf{B}_i)$  specifies the number of “long-run” relationships that exist among the domestic and the foreign variables. Note, however, that when  $(\mathbf{A}_i - \mathbf{B}_i)$  is rank deficient and  $\mathbf{a}_{i,1}$  is unrestricted, the linear trend coefficient  $\mathbf{a}_{i,1}$  may induce a quadratic trend in  $\mathbf{x}_{i,t}$ . Such a trending behavior is clearly undesirable. To avoid this problem, a restriction on the trend coefficient,

$$\mathbf{a}_{i,1} = (\mathbf{A}_i - \mathbf{B}_i) \boldsymbol{\kappa}_{i,1},$$

is thus imposed; cf. Harbo et al. (1998) and Pesaran et al. (2000). Under this restriction, equation (3) becomes

$$\begin{aligned} \Delta \mathbf{x}_{i,t} = & \boldsymbol{\kappa}_{i,0} - \mathbf{\Pi}_i (\boldsymbol{\xi}_{i,t-1} - \boldsymbol{\kappa}_{i,1} (t-1)) \\ & - \mathbf{\Phi}_{i,2} \Delta \mathbf{x}_{i,t-1} + \mathbf{\Psi}_{i,0} \Delta \mathbf{x}_{i,t}^* + \mathbf{\Gamma}_{i,0} \Delta \mathbf{d}_t + \varepsilon_{i,t}, \end{aligned} \quad (4)$$

where  $\mathbf{\Pi}_i = (\mathbf{A}_i - \mathbf{B}_i, -\mathbf{\Gamma}_{i,0} - \mathbf{\Gamma}_{i,1})$ ,  $\boldsymbol{\xi}_{i,t} = (\mathbf{z}'_{i,t}, \mathbf{d}'_t)'$  and  $\boldsymbol{\kappa}_{i,0} = \mathbf{a}_{i,0} + \mathbf{\Pi}_i \boldsymbol{\kappa}_{i,1}$ . Here,  $\boldsymbol{\kappa}_{i,0}$  is a unrestricted constant.

In view of equation (4), the information regarding the long-run co-integration relations between  $\mathbf{x}_{i,t}$ ,  $\mathbf{x}^*_{i,t}$  and  $\mathbf{d}_t$  are contained in the  $m_i \times (m_i + m_i^* + m_d)$  matrix of  $\mathbf{\Pi}_i = \boldsymbol{\alpha}_i \boldsymbol{\beta}'_i$ , where  $\boldsymbol{\alpha}_i$  is the  $m_i \times \ddot{r}_i$  loading matrix with  $\ddot{r}_i = \text{rank}(\mathbf{\Pi}_i)$  and  $\boldsymbol{\beta}_i$  is the  $(m_i + m_i^* + m_d) \times \ddot{r}_i$  matrix of co-integrating vectors. As shown by Harbo et al. (1998), the equation (4) only contains partial information about the co-integrating relations  $\boldsymbol{\beta}_i$ . Only when  $\mathbf{x}^*_{i,t}$  and  $\mathbf{d}_t$  are weakly exogenous for  $\boldsymbol{\beta}_i$ , can equation (4) be used to make efficient inference on the co-integrating relations  $\boldsymbol{\beta}_i$ . Note that these weak exogeneity assumptions imply no long-run feedback from  $\mathbf{x}_{i,t}$  to  $\mathbf{x}^*_{i,t}$ , and do not preclude  $\mathbf{x}_{i,t}$  being Granger-causal for  $\mathbf{x}^*_{i,t}$  in the short run.<sup>3</sup> In our empirical studies, the rank of the co-integrating space for each country is computed using Johansen’s trace eigenvalue statistic, and the parameters  $\boldsymbol{\beta}_i$  in the country-specific submodels are estimated

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<sup>3</sup>In this case  $\mathbf{x}^*_{i,t}$  is said to be “long-run forcing” for  $\mathbf{x}_{i,t}$ , which implies that the error-correction term in equation (4) does not enter in the marginal model of  $\mathbf{x}^*_{i,t}$ .



using the reduced-rank procedure of Harbo et al. (1998), given that weak exogeneity assumptions hold for all countries. Conditional on a given estimate of  $\beta_i$ , the remaining parameters in country-specific submodels are estimated by OLS regressions of  $\Delta \mathbf{x}_{i,t}$  on intercepts, the error-correction terms,  $\Delta \mathbf{x}_{i,t}$ ,  $\Delta \mathbf{x}_{i,t}^*$ ,  $\Delta \mathbf{d}_t$  and their lagged values. After the country-specific models are estimated, the weak exogeneity assumptions are statistically evaluated using the procedure of Harbo et al. (1998).

In the second step, we combine the country-specific submodels into a global representation. We collect all of the country-specific variables in the  $M \times 1$  vector  $\mathbf{x}_t = (\mathbf{x}'_{0,t}, \mathbf{x}'_{1,t}, \dots, \mathbf{x}'_{N,t})'$  with  $M = \sum_{i=0}^N m_i$ . We then write the country-specific variable in terms of  $\mathbf{x}_t$ :

$$\mathbf{z}_{i,t} = \mathbf{W}_i \mathbf{x}_t, \quad i = 0, 1, \dots, N,$$

where  $\mathbf{W}_i$  is an  $(m_i + m_i^*) \times M$  matrix of fixed and known constants defined in terms of the country-specific weights  $w_{i,j}$ ; see, e.g., Pesaran et al. (2004) for details. As an example, we re-write the estimated VARX(2,1) model for country  $i$  as

$$\hat{\mathbf{A}}_i \mathbf{z}_{i,t} = \hat{\mathbf{a}}_{i,0} + \hat{\mathbf{a}}_{i,1} t + \hat{\mathbf{C}}_i \mathbf{z}_{i,t-1} + \hat{\mathbf{D}}_i \mathbf{z}_{i,t-2} + \hat{\mathbf{\Gamma}}_{i,0} \mathbf{d}_t + \hat{\mathbf{\Gamma}}_{i,1} \mathbf{d}_{t-1} + \hat{\boldsymbol{\varepsilon}}_{i,t},$$

where  $\hat{\mathbf{C}}_i = (\hat{\mathbf{\Phi}}_{i,1}, \hat{\mathbf{\Psi}}_{i,1})$  and  $\hat{\mathbf{D}}_i = (\hat{\mathbf{\Phi}}_{i,2}, \mathbf{0})$ . Assuming that  $0 \leq \check{p}_i \leq 2$  and  $0 \leq \check{q}_i \leq 1$  for all  $i$  and stacking these country-specific equations all together, we have

$$\hat{\mathbf{A}} \mathbf{x}_t = \hat{\mathbf{a}}_0 + \hat{\mathbf{a}}_1 t + \hat{\mathbf{C}} \mathbf{x}_{t-1} + \hat{\mathbf{D}} \mathbf{x}_{t-2} + \hat{\mathbf{\Gamma}}_0 \mathbf{d}_t + \hat{\mathbf{\Gamma}}_1 \mathbf{d}_{t-1} + \hat{\boldsymbol{\varepsilon}}_t,$$

where

$$\hat{\mathbf{a}}_0 = \begin{bmatrix} \hat{\mathbf{a}}_{0,0} \\ \hat{\mathbf{a}}_{1,0} \\ \vdots \\ \hat{\mathbf{a}}_{N,0} \end{bmatrix}, \quad \hat{\mathbf{a}}_1 = \begin{bmatrix} \hat{\mathbf{a}}_{0,1} \\ \hat{\mathbf{a}}_{1,1} \\ \vdots \\ \hat{\mathbf{a}}_{N,1} \end{bmatrix}, \quad \hat{\mathbf{\Gamma}}_0 = \begin{bmatrix} \hat{\mathbf{\Gamma}}_{0,0} \\ \hat{\mathbf{\Gamma}}_{1,0} \\ \vdots \\ \hat{\mathbf{\Gamma}}_{N,0} \end{bmatrix}, \quad \hat{\mathbf{\Gamma}}_1 = \begin{bmatrix} \hat{\mathbf{\Gamma}}_{0,1} \\ \hat{\mathbf{\Gamma}}_{1,1} \\ \vdots \\ \hat{\mathbf{\Gamma}}_{N,1} \end{bmatrix}$$

and

$$\hat{\mathbf{A}} = \begin{bmatrix} \hat{\mathbf{A}}_0 \mathbf{W}_0 \\ \hat{\mathbf{A}}_1 \mathbf{W}_1 \\ \vdots \\ \hat{\mathbf{A}}_N \mathbf{W}_N \end{bmatrix}, \quad \hat{\mathbf{C}} = \begin{bmatrix} \hat{\mathbf{C}}_0 \mathbf{W}_0 \\ \hat{\mathbf{C}}_1 \mathbf{W}_1 \\ \vdots \\ \hat{\mathbf{C}}_N \mathbf{W}_N \end{bmatrix}, \quad \hat{\mathbf{D}} = \begin{bmatrix} \hat{\mathbf{D}}_0 \mathbf{W}_0 \\ \hat{\mathbf{D}}_1 \mathbf{W}_1 \\ \vdots \\ \hat{\mathbf{D}}_N \mathbf{W}_N \end{bmatrix}, \quad \hat{\boldsymbol{\varepsilon}}_t = \begin{bmatrix} \hat{\boldsymbol{\varepsilon}}_{0,t} \\ \hat{\boldsymbol{\varepsilon}}_{1,t} \\ \vdots \\ \hat{\boldsymbol{\varepsilon}}_{N,t} \end{bmatrix}.$$

Then  $\mathbf{x}_t$  can be written as

$$\mathbf{x}_t = \hat{\mathbf{A}}^{-1}(\hat{\mathbf{a}}_0 + \hat{\mathbf{a}}_1 t + \hat{\mathbf{C}}\mathbf{x}_{t-1} + \hat{\mathbf{D}}\mathbf{x}_{t-2} + \hat{\mathbf{\Gamma}}_0 \mathbf{d}_t + \hat{\mathbf{\Gamma}}_1 \mathbf{d}_{t-1} + \hat{\boldsymbol{\varepsilon}}_t),$$

which may be solved recursively forward to obtain the future values of  $\mathbf{x}_t$ .

## 2.2 Model Inference

As discussed earlier, the main assumption underlying GVAR estimation is the weak exogeneity of  $\mathbf{x}_{i,t}^*$  with respect to the co-integrating relations  $\boldsymbol{\beta}_i$ . Following Johansen (1992) and Harbo et al. (1998), a formal test of this assumption is statistically evaluated by running an auxiliary regression:

$$\Delta \mathbf{x}_{i,t}^* = \boldsymbol{\kappa}_{i,t}^* + \sum_{j=1}^{\check{r}_i} \boldsymbol{\alpha}_{i,j}^* \hat{\boldsymbol{\delta}}_{i,j,t-1} + \sum_{j=1}^{\check{p}_i^*} \boldsymbol{\Phi}_{i,j}^* \Delta \mathbf{x}_{i,t-j} + \sum_{j=1}^{\check{q}_i^*} \boldsymbol{\Psi}_{i,j}^* \Delta \mathbf{x}_{i,t-j}^* + \boldsymbol{\varepsilon}_{i,t}^*, \quad (5)$$

where  $\hat{\boldsymbol{\delta}}_{i,j,t-1} = \hat{\boldsymbol{\beta}}_{i,j}'(\boldsymbol{\xi}_{i,t-1} - \hat{\boldsymbol{\kappa}}_{i,1}(t-1))$ ,  $j = 1, 2, \dots, \check{r}_i$ , are the estimated error-correction terms corresponding to the  $\check{r}_i$  co-integrating relations found for the  $i^{\text{th}}$  country submodel, and  $\hat{\boldsymbol{\beta}}_{i,j}$  denotes the  $j^{\text{th}}$  co-integrating vector for country  $i$ . The test for weak exogeneity is an  $F$ -test of the joint hypothesis that  $\boldsymbol{\alpha}_{i,j}^* = 0$ ,  $j = 1, 2, \dots, \check{r}_i$ , in equation (5). For simplicity, the lag orders are set to be  $\check{p}_i^* = \check{p}_i$  and  $\check{q}_i^* = \check{q}_i$  for all countries in the empirical applications.<sup>4</sup>

To analyze the dynamic properties of the global model, we follow Pesaran et al. (2004) and use generalized impulse response functions (GIRFs). GIRFs, recently introduced by Koop et al. (1996), are an alternative to the orthogonalized impulse response functions (OIRFs) proposed by Sims (1980) in the VAR literature. While OIRFs depend on a set of orthogonalized shocks, the GIRFs consider the shock to an individual error and integrate out the effects of the other shocks based on the historical distributions of all errors. Unlike OIRFs, GIRFs neither require imposing identification restrictions, nor are they variant to the ordering of the endogenous variables in the vector  $\mathbf{x}_t$ . These two properties of GIRF are important considerations in our GVAR model.

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<sup>4</sup>Pesaran et al. (2004) also indicate three requirements as sufficient conditions for the validity of the GVAR model: (i) the model must be dynamically stable, (ii) the weights must be relatively small, and (iii) the cross-dependence of the shocks must be small. All these conditions are satisfied in our model.

Table 1: Countries and Regions in the GVAR Model

<b>China</b>	<b>Developed Economies</b>	<b>Latin America</b>
<b>Japan</b>	Australia	Argentina
<b>USA</b>	Canada	Brazil
<b>UK</b>	New Zealand	Chile
		Mexico
<b>Euro Area</b>	<b>Rest of Asia</b>	
Austria	Taiwan	<b>Rest of the World</b>
Belgium	Hong Kong	India
Germany	Indonesia	Turkey
France	Korea	Saudi Arabia
Finland	Malaysia	South Africa
Italy	Philippines	
Netherlands	Singapore	<b>Rest of W. Europe</b>
Spain	Thailand	Sweden
		Switzerland

### 3 Estimation and Testing of the Model

#### 3.1 Data Considerations and Unit-Root Tests

Our GVAR model includes 33 countries, where the euro area are considered as a single economy (eight countries that originally joined the euro on 1 January 1999 are grouped into one). The time series data for the euro area are constructed as cross section weighted averages over Austria, Belgium, Germany, France, Finland, Italy, Netherlands and Spain using average purchasing power parity GDP weights over the period of 2006–2008. Therefore, the present GVAR model contains 26 countries/regions; see Table 1 for details. Note that the countries in our GVAR model accounts for almost 90% of the world GDP and nearly two-thirds of total exports around the world. Since the paper aims to evaluate the impact of external shocks on Taiwan’s economy, we concentrate our presentation of the results on those countries and regions with special relevance to Taiwan – namely, U.S., China, Japan, euro area and Taiwan itself. A more extensive set of results are available from the authors upon request.

In our empirical study, most country-specific submodels include the following do-

mestic core variables:<sup>5</sup>

$$\begin{aligned} y_{i,t} &= \ln(\text{GDP}_{i,t}/\text{CPI}_{i,t}), & p_{i,t} &= \ln(\text{CPI}_{i,t}), \\ q_{i,t} &= \ln(\text{Q}_{i,t}/\text{CPI}_{i,t}), & e_{i,t} &= \ln(\text{E}_{i,t}) - \ln(\text{CPI}_{i,t}), \\ r_{i,t} &= 0.25 \times \ln(1 + \text{R}_{i,t}/100), & u_{i,t} &= \text{U}_{i,t}, \end{aligned}$$

where  $y_{i,t}, p_{i,t}, q_{i,t}, e_{i,t}, r_{i,t}$  and  $u_{i,t}$  represent real output, price level, real equity price, real exchange rate, short-run interest rate and unemployment rate for country  $i$ , respectively. The term  $\text{GDP}_{i,t}$  denotes the nominal GDP,  $\text{CPI}_{i,t}$  denotes the consumer price index,  $\text{Q}_{i,t}$  denotes the nominal equity price index (e.g., S&P500 index in the U.S.),  $\text{E}_{i,t}$  denotes the exchange rate in terms of U.S. dollars,  $\text{R}_{i,t}$  denotes the interest rate and  $\text{U}_{i,t}$  denotes the unemployment rate. With the exception of the U.S. submodel, almost all regional submodels include the foreign variables:  $y_{i,t}^*, p_{i,t}^*, q_{i,t}^*, r_{i,t}^*, u_{i,t}^*$ , and the logarithm of oil prices  $p_t^o$ . Following Dees et al. (2007), the U.S.-specific foreign variables  $q_{US,t}^*$  and  $r_{US,t}^*$  are excluded in the U.S. submodel, while the logarithm of oil price  $p_t^o$  is included as an endogenous variable for U.S. economy. Due to insufficient data, the real equity price  $q_{i,t}$  is not included in China and other countries. Table 2 summarizes domestic and foreign variables included in the country-specific submodels. To take account of more recent economic events, the submodels are estimated over the period 1981:I–2008:IV. Full details of the data sources are available and upon request.

Before estimating the submodels, we first verify whether the variables included are integrated of order one (hereafter I(1)). In order to do so, the efficient ADF-GLS test of Elliott et al. (1996) is applied. Here, the maximum lag length for the ADF-GLS test is given by 6 and the appropriate lag length is selected by the modified information criterion of Ng and Perron (2001). The results of the ADF-GLS statistics for the variables of selected countries (i.e., U.S. China, Japan, euro area and Taiwan) can be found in Table 3. Generally speaking, the results of these tests show that the series are I(1) across all countries with only a few exceptions. For example, in the case of China, the ADF-GLS statistics seems to suggest that real output could be I(2). This is clearly implausible and could be due to poor data quality in China. In addition, real output in

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<sup>5</sup>Due to insufficient data availability, and the fact that not all countries have well developed capital markets, not all countries contain the same set of domestic core variables. For example, the real equity price  $q_{i,t}$  is not included in Argentina, Brazil, China, Indonesia, Mexico, Saudi Arabia, Switzerland and Turkey while the interest rate  $r_{i,t}$  is excluded in Saudi Arabia.

Table 2: Domestic and Foreign Variables Included in the Country-Specific Models

Variables	U.S.		All Countries Excluding U.S.	
	Endogenous	Foreign	Endogenous	Foreign
Real Output	$y_{us,t}$	$y_{us,t}^*$	$y_{i,t}$	$y_{i,t}^*$
Price Level	$p_{us,t}$	$p_{us,t}^*$	$p_{i,t}$	$p_{i,t}^*$
Real Exchange Rate	—	$e_{us,t}^*$	$e_{i,t}$	—
Real Equity Price	$q_{us,t}$	—	$q_{i,t}$	$q_{i,t}^*$
Interest Rate	$r_{us,t}$	—	$r_{i,t}$	$r_{i,t}^*$
Unemployment Rate	$u_{us,t}$	$u_{us,t}^*$	$u_{i,t}$	$u_{i,t}^*$
Oil Price	$p_{us,t}^o$	—	—	$p_{us,t}^o$

Note: Due to insufficient data availability, not all countries contain the same set of domestic core variables. For example, the real equity price  $q_{i,t}$  is not included in Argentina, Brazil, China, Indonesia, Mexico, Saudi Arabia, Switzerland and Turkey, while the interest rate  $r_{i,t}$  is excluded in Saudi Arabia.

U.K. appears borderline I(0)/I(1) according to the ADF-GLS statistics, although ADF test indicates that U.K. real output is I(1). Besides, in the cases of Argentina, Brazil, Chile, Mexico and South Africa, the test results indicate an I(2) process of the price level, which is not appropriate for our purpose. To circumvent this problem, we follow Pesaran et al. (2004) and use inflation rates  $\pi_{i,t} = p_{i,t} - p_{i,t-1}$  and  $\pi_{i,t}^* = p_{i,t}^* - p_{i,t-1}^*$ , instead of  $p_{i,t}$  and  $p_{i,t}^*$ , in all countries for subsequent analysis.

### 3.2 Estimation of the Regional Submodels

The next step of the analysis is to estimate regional submodels and identify the rank of their co-integrating space under the assumption that the country-specific foreign variables are weakly exogenous I(1) variables. For each country-specific VARX( $\ddot{p}_i, \ddot{q}_i$ ) model, a corresponding error-correction specification with unrestricted intercepts and restricted trend coefficients is derived. The error-correction model is then estimated subject to reduced-rank procedure of Harbo et al. (1998). Note that the order of the model is selected according to the Akaike Information Criterion (AIC) with  $\ddot{p}_{\max,i}$  and  $\ddot{q}_{\max,i}$  no greater than 2. The program is written in GAUSS, which is a modified version of Dees et al.'s (2007) estimation algorithm.

Table 4 summarizes the lag orders and the number of co-integrating relations for the set of selected countries. This table shows that for most countries a VARX(2,1)

Table 3: ADF-GLS Unit Root Test Statistics

Variables	U.S.	China	Japan	Euro Area	Taiwan
$y_{i,t}$	-1.464	-2.685	-2.865	-0.838	0.852
$\pi_{i,t}$	-0.040	-0.158	0.032	1.058	-0.894
$e_{i,t}$	—	-0.230	-1.602	-1.408	-0.868
$q_{i,t}$	-0.857	—	-0.856	-0.536	-1.517
$r_{i,t}$	0.957	-0.709	0.633	0.352	-0.606
$u_{i,t}$	-0.787	-1.290	-0.736	0.147	-1.717
$y_{i,t}^*$	-2.324	0.095	-1.636	-1.318	-1.256
$\pi_{i,t}^*$	1.591	1.208	1.135	1.505	1.079
$q_{i,t}^*$	—	-0.555	-0.685	-0.176	-0.660
$r_{i,t}^*$	—	-1.762	-0.334	-1.129	-0.100
$u_{i,t}^*$	-1.156	-1.075	-1.376	-1.035	-1.180

Note: The ADF-GLS statistics for all the level variables are based on regressions including a linear trend, except for the interest variables and unemployment rates. The 95% critical value of the ADF-GLS statistics for regressions with trend is  $-2.991$ , and for regressions without trend  $-1.943$ .

specification seems to be satisfactory. For the U.S. and the euro area, however, a VARX(2,2) is favoured by the AIC. In Table 4, it can also be seen that the number of co-integrating relations are 3 for the U.S. and Taiwan and 2 for Japan and the euro area. These results indicate that the long-run relationships make an important contribution in most country and that the error-correction terms provide for a complex and statistically significant set of interactions and feedbacks across domestic and foreign variables.

One of the key assumptions underlying our estimation approach is the weak exogeneity of the foreign variables. As noted earlier, the test for weak exogeneity is an  $F$ -test of the joint hypothesis that the coefficients of the co-integrating relations in equation (5) should be close to zero. These testing results for the set of selected countries are summarized in Table 5. From the results, we found that the weak exogeneity assumptions are not rejected for all the foreign variables in selected countries. In addition, for all the countries considered in this paper, only 8 out of 154 exogeneity tests turned out to be statistically significant.<sup>6</sup> Similar results can also be found in Dees et

<sup>6</sup>These are  $y_{i,t}^*$  for Mexico,  $\pi_{i,t}^*$  for Switzerland and Chile,  $q_{i,t}^*$  for Korea,  $r_{i,t}^*$  for Switzerland, Singapore, and Mexico and  $p_t^o$  for Hong Kong.

Table 4: VARX Order and Number of Co-integration Relationships

VARX( $\check{p}, \check{q}$ )	U.S.	China	Japan	Euro Area	Taiwan
$\check{p}$	2	2	2	2	2
$\check{q}$	2	1	1	2	1
# Co-integration	3	1	2	2	3

al. (2007). Since for most of the cases, the exogeneity hypothesis could not be rejected, implying that the foreign variables can be considered as weakly exogenous.

### 3.3 Impact Elasticities

From the estimation of each country-specific VARX model, we obtain estimates of the contemporaneous foreign variable coefficients. These coefficients, which are also called the “impact elasticities”, measure the contemporaneous change in a domestic variable given an exogenous one percent change in its foreign counterpart. Impact elasticities are particularly useful because they allow us to measure the co-movement of variables across countries. In Table 6, estimates of the impact elasticities of the selected countries are reported, along with the corresponding  $t$ -ratio calculated using the White’s heteroskedasticity-consistent variance estimator.

Generally speaking, the real equity price impact elasticities are statistically significant for most of the countries. All the values are positive, which indicate strong co-movement in equity prices across countries. These findings further suggest a strong synchronization of the GIRFs associated with changes in real equity prices across countries. Estimated real GDP impact elasticities are also statistically significant in 16 countries, including export-oriented economies, such as Taiwan, Hong Kong, Korea and Malaysia. We found no striking evidence of linkages among interest rates and unemployment rates across countries. In fact, impact elasticity estimates are seldom found to be statistically significant for these variables. As for inflation rates, coefficient estimates are not statistically significant in all 26 countries, and there is no evidence of international linkages across countries.

Table 5:  $F$ -Statistics for Testing the Weak Exogeneity of the Foreign Variables

	U.S.	China	Japan	Euro Area	Taiwan
$F$ -Statistics	$F(3,86)$	$F(1,84)$	$F(2,85)$	$F(2,79)$	$F(3,78)$
$y_{i,t}^*$	1.552	2.162	1.639	2.186	0.439
$\pi_{i,t}^*$	0.128	1.425	0.200	0.444	0.461
$q_{i,t}^*$	—	0.118	2.062	1.422	0.632
$r_{i,t}^*$	—	0.002	0.776	1.005	0.607
$u_{i,t}^*$	1.147	0.360	1.625	0.347	0.600
$p_t^o$	—	0.038	0.293	0.276	1.187

## 4 Impulse Response Analysis

To study the dynamic properties of the GVAR model, we investigate the implications of six different external shocks: (1) a one standard error increase in oil prices; (2) a one standard error decline in U.S. real output; (3) a one standard error decline in U.S. equity prices; (4) a one standard error increase in U.S. interest rates; (5) a one standard error decline in China real output; and (6) a one standard error decline in Taiwan’s real output.<sup>7</sup>

### 4.1 Shock to Oil Prices

Figure 1 displays the estimated GIRFs of a one standard error increase in the price of oil on several selected economic variables. The solid line in the top-left panel reports the bootstrap mean estimates of the dynamic response functions, while dashed lines denote a 90% confidence interval for the dynamic response functions. As shown in this panel, the shock amounts to a rise in the oil prices of 6.7% per quarter in the long run. The high persistence in the oil price behavior can be attributed to the data series being integrated of order unity. In addition, this shock has a significant positive effect on the inflation rate in the short run in Taiwan and most selected countries, increasing inflation rate by around 0.11% (see the top-right panel in Figure 1). As

<sup>7</sup>Given the large number of countries in our example, many possible simulations could be performed. However, to keep this paper within reasonable space limits, we choose to show only 6 examples to illustrate the way our model can be used. Also, we may only report the results of the countries which are more relevant to Taiwan.



Table 6: Contemporaneous Effects of Foreign Variables on their Domestic Counterparts

Variables	U.S.	China	Japan	Euro Area	Taiwan
$y_{i,t}$	0.303* [3.773]	-0.028 [-0.356]	0.555* [2.016]	0.506* [2.699]	1.298* [4.066]
$\pi_{i,t}$	0.074 [1.228]	0.022 [0.262]	0.023 [0.383]	0.043 [1.428]	0.174 [1.035]
$q_{i,t}$	— —	— —	0.714* [6.045]	1.037* [11.500]	0.892* [3.626]
$r_{i,t}$	— —	-0.007 [-0.332]	0.025 [0.798]	0.061* [4.347]	0.010 [0.059]
$u_{i,t}$	0.302* [3.061]	0.605 [1.393]	0.445 [0.651]	0.277 [0.550]	0.161 [0.649]

Note: \* denotes statistical significance at the 5% level. White's heteroskedastic-robust  $t$ -ratios are given in square brackets.

for real GDP, the impacts of the oil price shock are negative in most countries; this is however significant in Taiwan only. As regards the real equity price and interest rate, not surprisingly, the increase in the oil prices adversely affects real equity prices in Taiwan and other selected countries, and applies upward pressure on the interest rates in the short run. The real exchange rate, however, does not react to the oil price shock and the associated GIRFs are insignificant in most countries in the long run; see the bottom-right panel of Figure 1. These results are consistent with those found in Dees et al. (2007).

## 4.2 Shock to U.S. Real Output

Figure 2 depicts the GIRFs for a one standard error decline in U.S. real output. This shock is equivalent to a decrease of about 0.22% U.S. real output per quarter. As we can see in the top-left panel, the U.S. output shock is highly persistent and leads to a sustained, statistically significant drop in the U.S. real GDP of 0.32% on impact. In addition, the effect of a decline in U.S. real output on U.S. unemployment rate is significant in the short run, with the unemployment rate staying up about 6 quarters after a shock. This result is consistent with our expectations and the existing macroeconomic literature. In contrast, we found that the response of U.S. inflation rate to a decline in U.S. real output is insignificant. A decline to U.S. real GDP may also imply

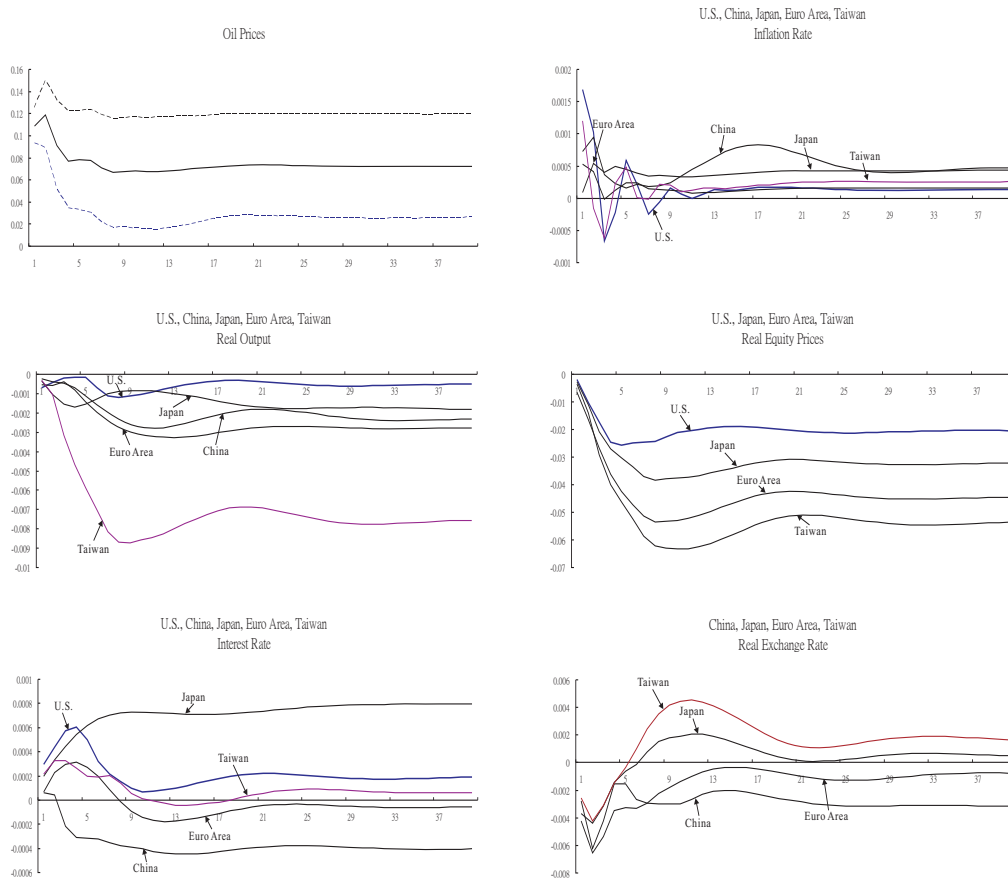


Figure 1: GIRFs of a One Standard Error Increase in Oil Prices

a decrease in the real output of many countries around the globe and a reduction in job opportunities in those countries whose economies in particular highly depend on the trade regime with U.S., such as Taiwan. For example, as shown in the middle-left panel of Figure 2, a decline in U.S. real GDP reduces the output in almost all selected foreign countries and these effects are especially large in the U.S. neighboring countries, such as Mexico and Canada. Also, the effects are strong for some countries, particularly the smaller Asian ones (e.g., Taiwan, Hong Kong and Singapore). Large Asian countries, such as Japan and China, appear to be relatively insulated from the shock. In addition, unemployment rates increase significantly in Taiwan and almost all selected countries, consistently with the declines in real outputs. The effects of a decline in U.S. real output on interest rates and inflation rates are ambiguously negative and insignificant

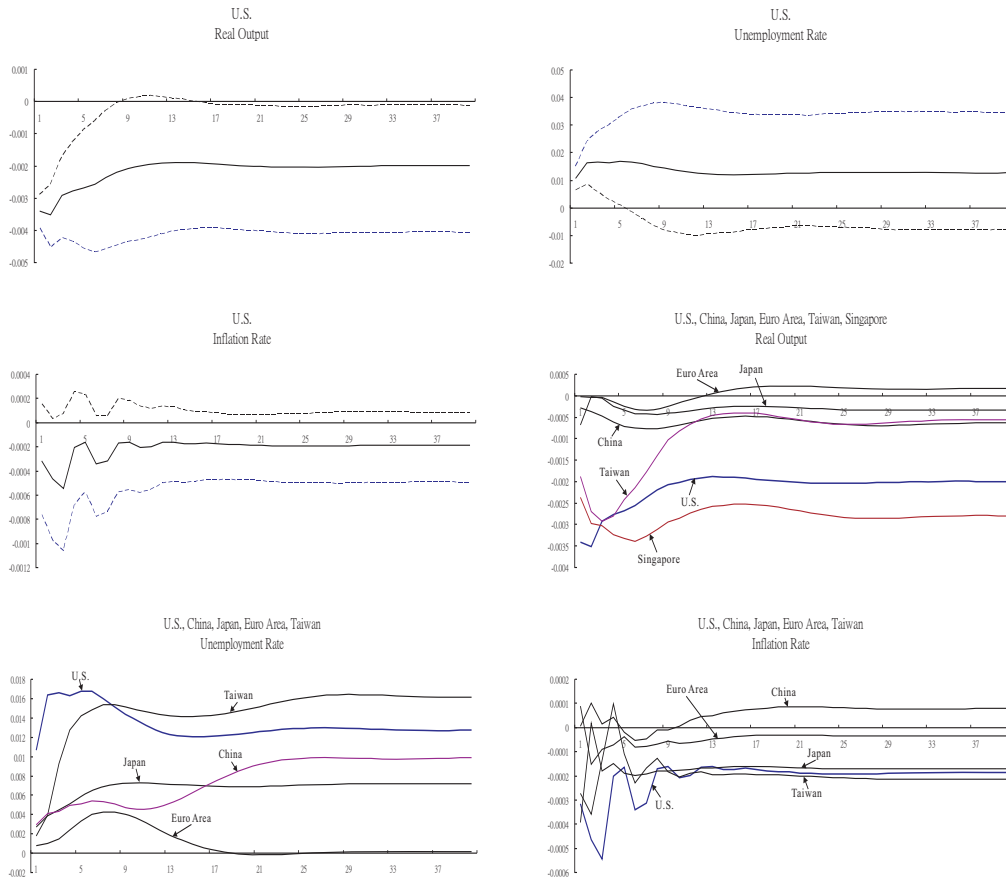


Figure 2: GIRFs of a One Standard Error Decline in U.S. Real Output

in most selected countries, however.

### 4.3 Shock to U.S. Real Equity Prices

Next, the dynamic effects of U.S. real equity prices are plotted in Figure 3. A one standard error decline in U.S. real equity prices, which amounts to a decrease by 3.5% on impact and by around 1.5% in the long-run, has a significant negative effect on U.S. real output over quarters 1 to 4, with a maximum impact of -0.11%. Such impact is strong and significant on U.S. unemployment rate as well. The U.S. unemployment rate goes up by more than 1.2% over quarters 1 to 5. Also, due to the strong co-movement in the equity prices' dynamics across countries, the transmission of the shock to other countries seems to take place through the equity markets. Real equity prices drop in

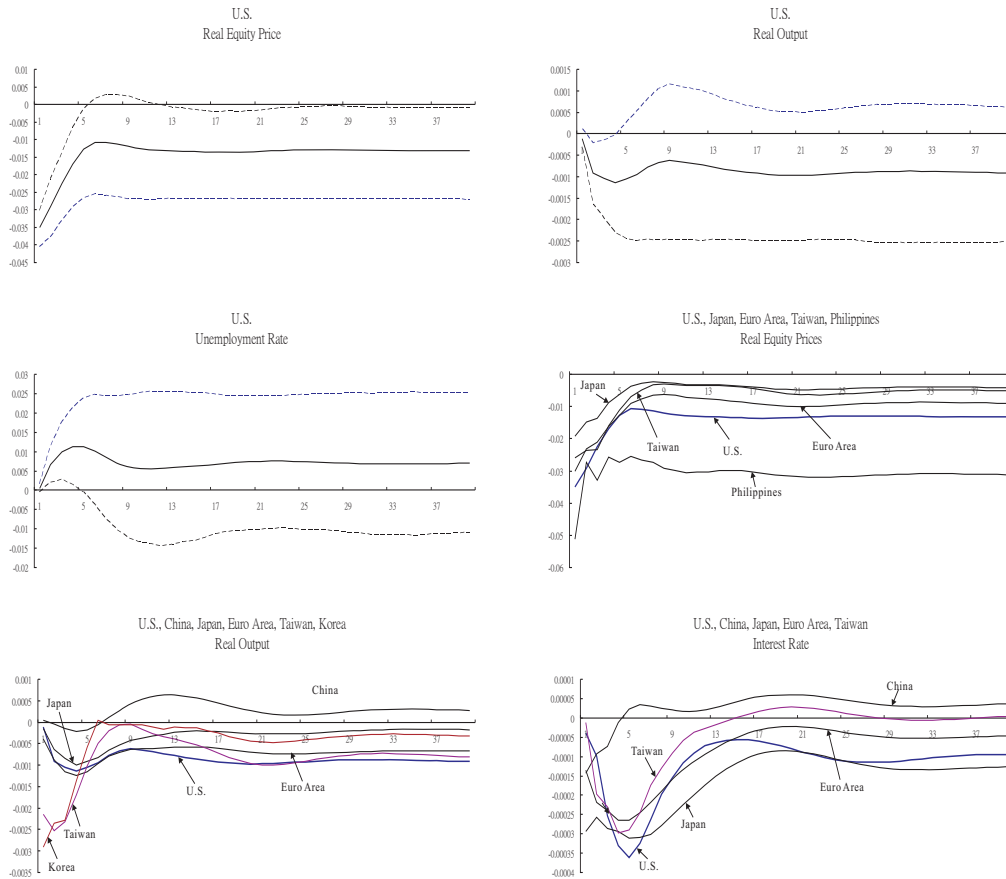


Figure 3: GIRFs of a One Standard Error Decline in U.S. Real Equity Price

Taiwan and most selected countries by a significant amount in the short run. Moreover, the magnitude of such impact in these countries is very close to the one in U.S. and even larger for the case in Philippines. The U.S. equity price shock does not significantly affect real output in the selected countries but the four Asian Tigers, Mexico, and Argentina. Finally, the impacts of a decline in U.S. real equity prices on interest rates in most selected countries seem to follow the response of U.S. interest rates to a decline in the U.S. real equity prices with a significant drop in the short run.

#### 4.4 Shock to U.S. Interest Rate

The GIRFs results of a one standard error increase in U.S. interest rate are displayed in Figure 4. This shock corresponds to an increase of 0.13% of U.S. interest rate on

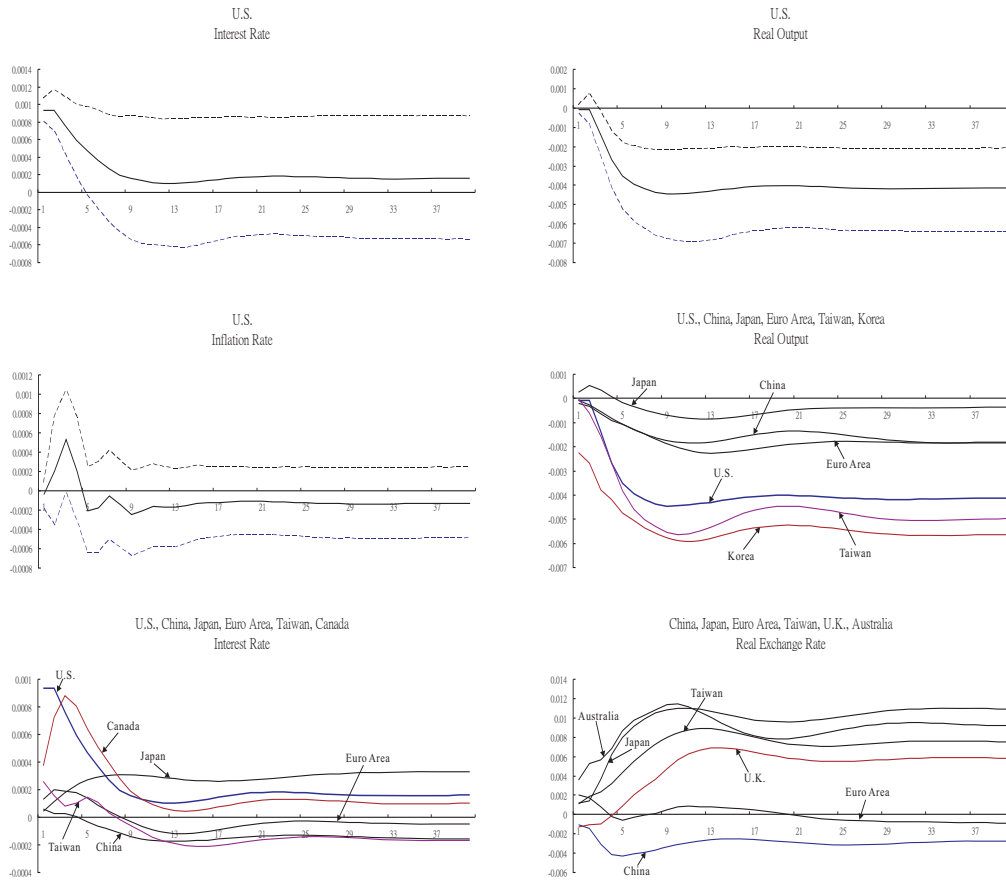


Figure 4: GIRFs of a One Standard Error Increase in U.S. Interest Rate

impact. As shown in the figure, there is a significant response to a monetary policy shock in U.S. real output. Compared with the results reported in Dees et al. (2007), the impacts in our results are stronger and more permanent. Regarding the effects of the shock on inflation rates, we found a price puzzle in the short run as Dees et al. (2007). However, this effect is insignificant and fades away rapidly. The impacts on the real output of Taiwan and other selected countries remain limited, and in most cases, insignificant. Real output drops significantly in responses to an increase in U.S. interest rate are only in Korea and New Zealand. Besides, the financial variables, including interest rate and real exchange rate, are barely affected by the U.S. monetary policy shock. As regards the transmission of the increases in U.S. interest rate, the central banks in other countries tend to slightly increase their interest rates though the

magnitude of such increases are not significant in Taiwan and most selected countries, with the exceptions of Canada and Hong Kong (see the bottom-left panel of Figure 4). As for the real exchange rates, such a positive shock to U.S. interest rate leads to an appreciation in the U.S. dollars, and therefore causes the real exchange rates to increase in Taiwan and many selected countries. The effects on the real exchange rates are all insignificant, however.

#### **4.5 Shock to China Real Output**

Since China is the world's second largest economy and Taiwan's main trading partner, the effect of a decline in China real output on macroeconomic variables in Taiwan and the rest of the world is of special interest to us. A decline in the domestic output in China, which corresponds to a decrease by about 0.8% in the short run and by around 0.6% in the longer run, is found to have statistically significant effects on China's interest rate over quarters 5 to 10 (see the top two panels of Figure 5). This shock also results in a higher inflation rate in China, a slight appreciation of RMB, and a decline in China's interest rate in the short run. However, these impacts are all insignificant. Besides, China's output shock does not affect macroeconomic activities in Taiwan and the rest of the world. The limited and insignificant effects on the real outputs, real equity prices and interest rates are found in Taiwan and most selected countries. These results may be attributed to the fact that China has just enjoyed his fast growth in the very recent years. The data used in our study is up to 2008:IV only, which may not be long enough to capture the impact of a shock to macroeconomic factors in China on the world as significantly as the one in U.S. does.

#### **4.6 Shock to Taiwan Real Output**

Figure 6 illustrates the GIRFs for a one standard error decline in Taiwan's real output. This shock is equivalent to a 0.43% decrease in Taiwan GDP. As shown in the top-right panel, the shock is highly persistent and thus the real GDP converges only slowly back to its mean. This negative output shock in Taiwan leads to a statistically significant 0.7% reduction in Taiwan's interest rate, while it amounts to a drop in Taiwan's real equity price of 4% over quarters 1 to 5. Such a negative shock increases Taiwan's unemployment rate as well as real exchange rate. In addition, this shock implies an

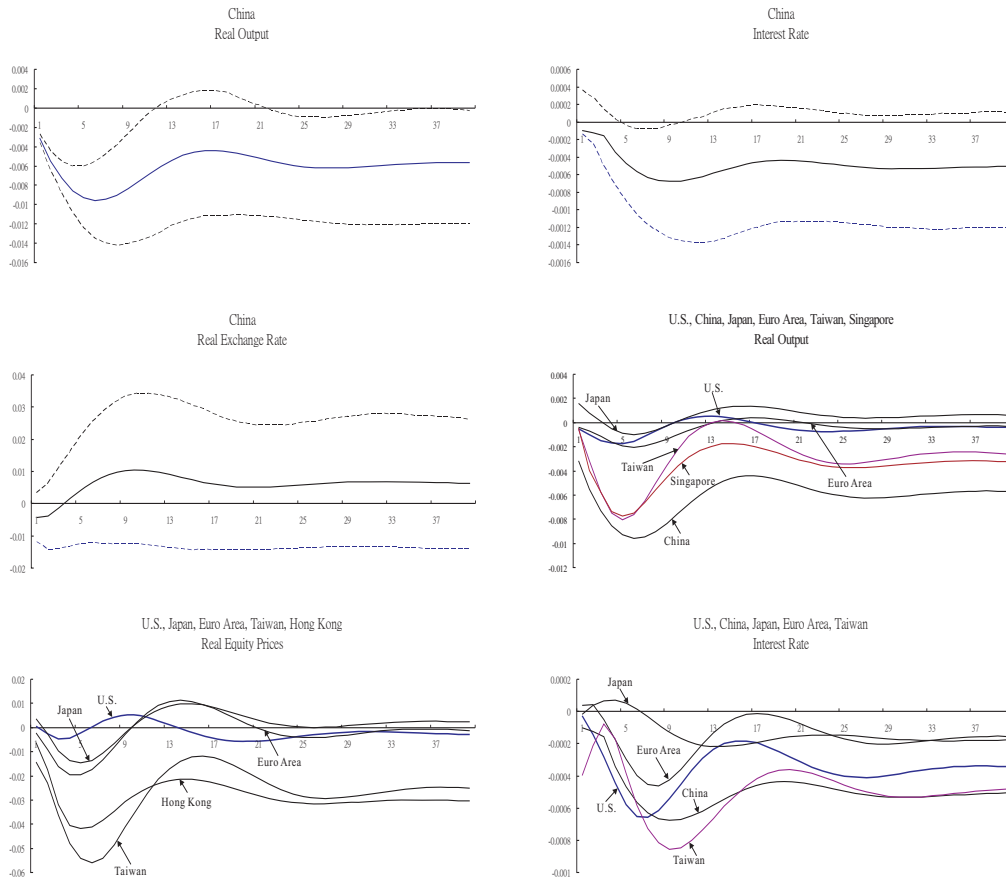


Figure 5: GIRFs of a One Standard Error Decline in China Real Output

immediate increase of 0.05% in Taiwan’s inflation rate and then a reduction in the inflation rate to the level of -0.1% one quarter later. Yet, the response of the inflation rate to a decline in Taiwan’s real output is insignificant. This result is consistent to the findings of Peng and Chou (2001), Lin (2003), and Chung and Chan (2008). However, in contrast to the models of Lin (2003) and Chung and Chan (2008), which mainly consider economic activities in Taiwan or in a small region, our GVAR model allows us to examine shock transmission mechanisms at the global level. Finally, the impacts of a decline in Taiwan’s real output on the macroeconomic variables in most countries are not significant.

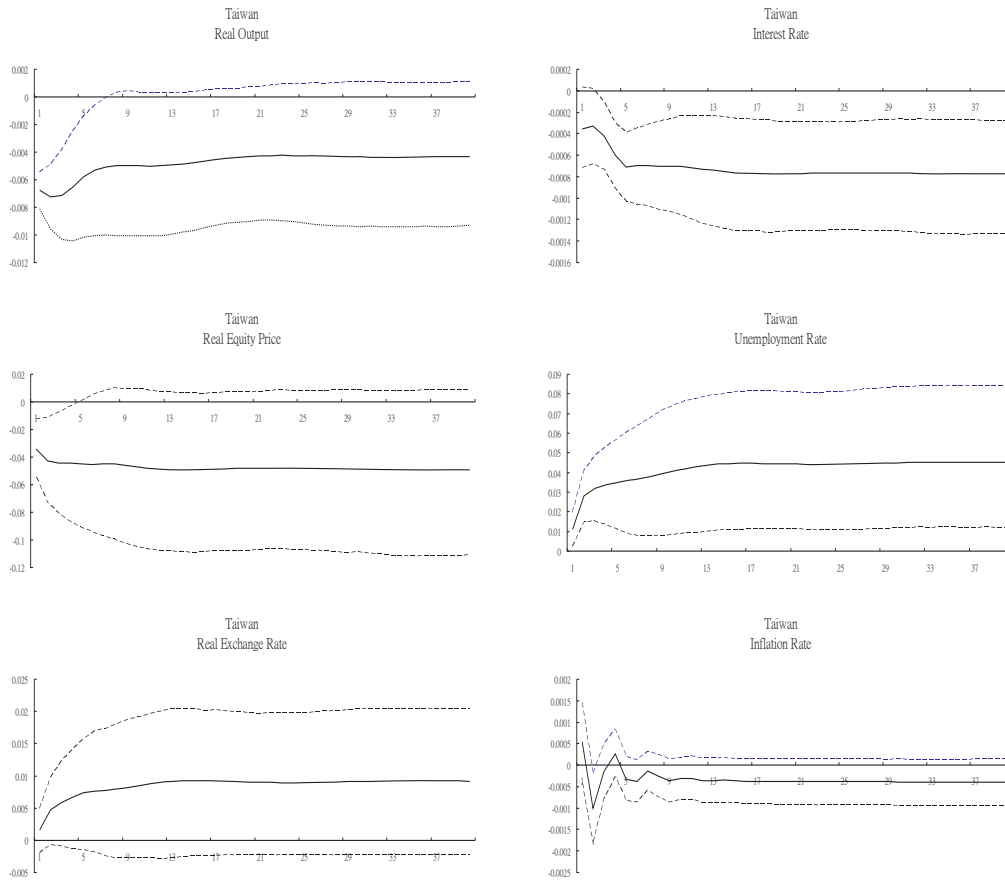


Figure 6: GIRFs of a One Standard Error Decline in Taiwan Real Output

## 5 Conclusion

Due to the increasing integration of financial and world commodity markets, there is growing interest among macroeconomists and policymakers in comprehending how economic conditions in one country may influence economic conditions in other countries. In this paper, our objective is to conduct a thorough evaluation on the international economic linkages between Taiwan and the rest of the world using the GVAR model proposed by Pesaran et al. (2004) and Dees et al. (2007). Specifically, we generalize the research of Dees et al. (2007) by including Taiwan and the other three Asian Tigers (i.e., Hong Kong, Korea and Singapore) in the GVAR model and by extending the model to longer sample period, 1981:I – 2008:IV. Thirty-three countries are represented in our



model. We focus our analysis on impulse responses generated by six different shocks, including an oil price shock, a U.S. real output shock, a U.S. equity price shock, a U.S. interest rate shock, a China real output shock and a Taiwan's real output shock. Our results suggest that the impacts of each shock on Taiwan and other selected economies are mostly consistent with macroeconomic theory and our expectations.

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