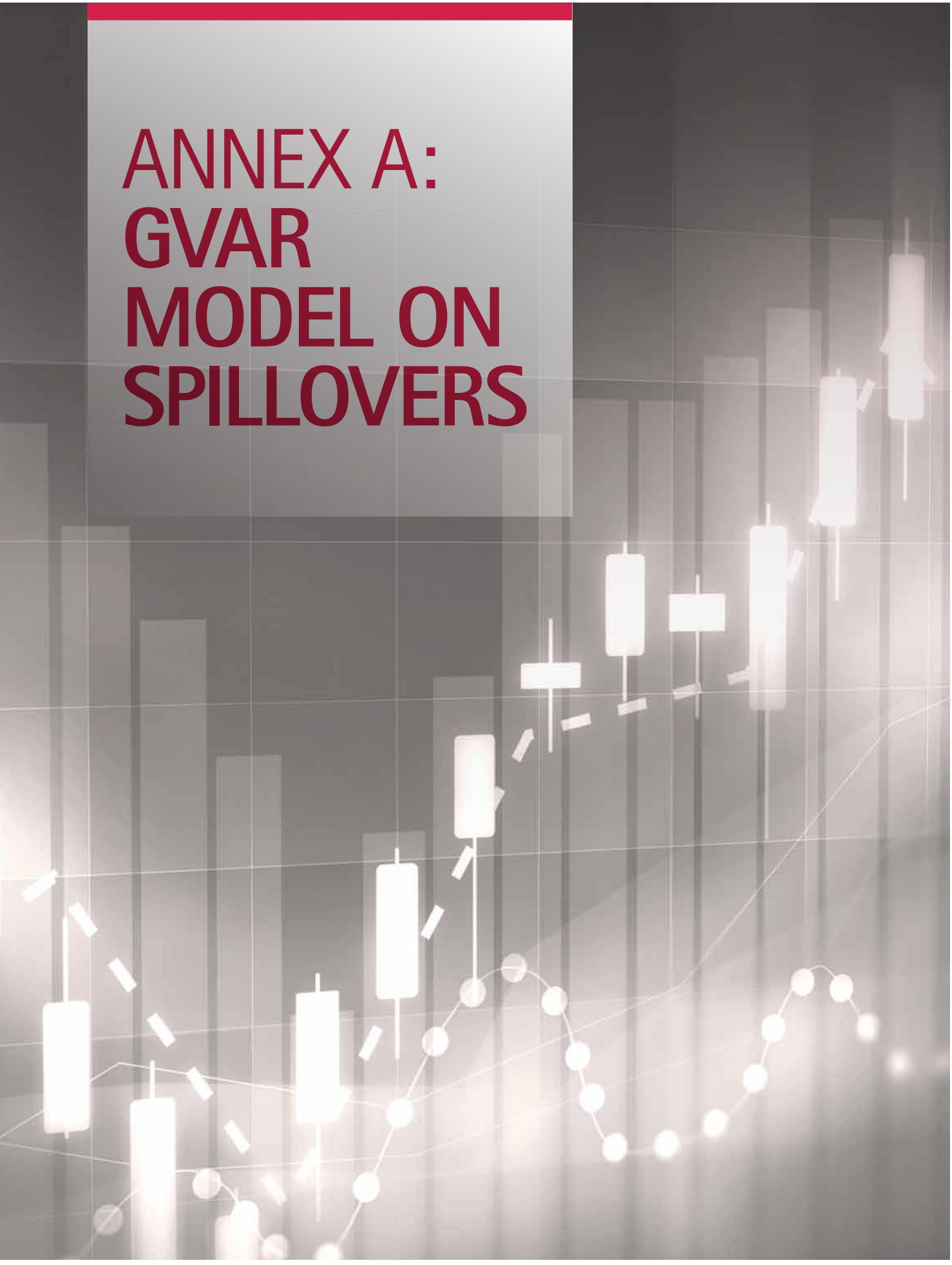
ANNEX A: GVAR MODEL ON SPILLOVERS



Annex: GVAR model on Spillovers

1.0 Introduction and a brief literature review of the GVAR[47]

The Global Vector Autoregressive (GVAR) model is commonly used to investigate the spillover effects of various international economic shocks on Asian economies. For this purpose, we use a time-series technique of the GVAR model, which was introduced by Pesaran, Schuermann, and Weiner (2004), Dees, di Mauro, Pesaran, and Smith (2007), and Dees, Holly, Pesaran, and Smith (2007). In this empirical study, two versions of the GVAR model are estimated; a Real Sector GVAR (to examine the propagation of shocks through trade linkages) and a Financial Sector GVAR (to examine the propagation of shocks through banks/corporates and equity market linkages).[48] In particular, the Real Sector GVAR aims to quantify the magnitude and diffusion process of unexpected shocks in the industrial production growth rate, imports, as well as short-term interest rate that originate in the U.S., China and Japan to the economic variables of 27 sample countries including ASEAN+3 economies. In contrast, the Financial Sector GVAR aims to quantify the magnitude and diffusion process of unexpected shocks in bank/corporate distress, short-term interest rate, and equity prices that originate in the U.S. China, Japan, as well as the U.K. to the same set of sample countries, excluding Brunei, Lao PDR and Myanmar due to some data gaps.

In general, the GVAR model is configured by a system of country-specific VAR models, each of which is connected through the so-called "foreign" variables in each sub VARs. A key idea is that the "foreign" variables are defined as a deterministic function of the other country's domestic variables. At the time of estimating the parameters, the country-specific VAR models are estimated one by one, by assuming that the "foreign" variables are indeed "exogenous." For the dynamic analysis, such as the impulse response analysis, the entire system is solved along with the identity equations that associate the "foreign" variables with the other country's "domestic" variables.

Due to its modeling flexibility, the GVAR model has been applied to various fields such as macroeconomics (Dees, di Mauro, Pesaran, and Smith, 2007), industrial sectors (Hiebert and Vansteenkiste, 2010), bond markets (Favero, 2013), real estate markets (Vansteenkiste, 2007), fiscal imbalance on borrowing costs (Caporale and Girardi, 2013), and U.S. credit supply shocks (Eickmeier and Ng, 2015). The model was also applied to examine the impact of China's recent slowdown (Gauvin and Rebillard, 2015; Inoue, Kaya, and Oshige, 2015), and the propagations of oil and food price shocks to nation's domestic price indices (Galesi and Lombardi, 2009) as well as the level of production (Inoue and Okimoto, 2016).

1.1 The Model

The i-th country-specific (VAR with exogenous variables) VARX*(***p, q***) model (for i = 1, ..., N), a building-block of the GVAR model, is specified as

$$\mathbf{\Phi}_i(L,p_i)\mathbf{x}_{i,t} = \boldsymbol{a}_{i0} + \boldsymbol{a}_{i1}t + \mathbf{\Lambda}_i(L,q_i)\mathbf{x}^*_{i,t} + \mathbf{\Psi}_i(L,q_i)\boldsymbol{\omega}_t + \mathbf{u}_{it} \qquad (1)$$

where $\mathbf{x}_{i,t}$ represents the domestic variable vector of country *i*; $\mathbf{x}^*_{i,t}$ denotes the foreign variable vector; ω_t represents a vector of global variables; $\boldsymbol{a}_{i0}$ and $\boldsymbol{a}_{i1}$ denote the coefficients of a constant and a time trend; p_i represents country i's lag length of domestic variables; q_i represents country i's lag length of foreign and global variables; L denotes the lag operator; $\mathbf{\Phi}_i(L,p_i)$; $\mathbf{\Lambda}_i(L,q_i)$, and $\mathbf{\Psi}_i(L,q_i)$ represent the polynomials of coefficient matrices with order p_i, q_i, and q_i; and $\mathbf{u}_{it}$ represents the idiosyncratic errors. A vector of country-specific shocks, $\mathbf{u}_{it}$, is assumed to be distributed as serially uncorrelated with zero mean and a nonsingular covariance matrix, i.e.,$\mathbf{u}_{it} \sim i.i.d.(0,\Sigma_{ii})$.

The element of foreign ("star") variable vector, $\mathbf{x}^*_{i,t}$, is constructed from the other country's domestic variables in the following manner. For time t, let us denote the first element of country i's foreign variable as $x^{*(1)}_{it}$ and the corresponding variable of country j as $x^{(1)}_{jt}$. They are linked by the weights, w_{ij}, which represent the "closeness" between country i and country j.

$$x^{*(1)}_{i,t} = \sum_{j=1}^{N} w_{ij}\ x^{(1)}_{jt} \qquad (2)$$

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[47] This Annex is the result of a joint study between AMRO and Professor Tomoo Inoue of Seikei University, Japan.
[48] This Financial GVAR extends the work done by Chen, Gray, N'Diaye, Oura, and Tamirisa (2010).

By definition, $w_{ii} = 0$, and $\sum_{j=1}^{N} w_{ij} = 1$ for i = 1, …, N. If the variable x_{jt} is missing for country j, then $\{w_{ij}\}_{i=1}^{N}$ is rescaled accordingly.[49]

For the Real Sector GVAR, for the closeness matrix w_{ij}, we use the trade weights (or trade shares) for each sample country (for Real Sector GVAR). For country i, its trade weight w_{ij} with respect to country j is quantified as:

$$w_{ij} = \frac{\text{sample average bilateral trade flows between countries } i \text{ and } j}{\sum_{k=1}^{N} \text{sample average bilateral trade flows between countries } i \text{ and } k} \quad (3)$$

where the "bilateral trade flow" is the sum of exports and imports between a pair of countries, obtained from the IMF's Direction of Trade Statistics. We take a sample average of years 2001-2015 of trade flows.[50]

For the Financial GVAR, for the closeness matrix w_{ij}, we use the financial stock weights for each sample country. For country i, its financial weight w_{ij} with respect to country j is quantified as:

$$w_{ij} = \frac{\text{sample average of financial stock in country } i \text{ from country } j}{\sum_{k=1}^{N} \text{sample average financial stock in country } i \text{ from country } k} \quad (4)$$

where the "financial stock" is the sum of Inward FDI (obtained from the Coordinated Direct Investment Survey, IMF) and the Assets of Total Investment (from the Coordinated Portfolio Investment Survey, IMF). Any negative inward FDI figures are replaced with zero. For the FDI and the portfolio investment, we take a sample average of years 2008-2015 and 2001-2015, respectively.

The dynamics of the global variables, $\boldsymbol{\omega}_t$, is specified as a following VARX(p, q) model:

$$\boldsymbol{\Phi}(L,p)\boldsymbol{\omega}_t = \boldsymbol{\mu}_0 + \boldsymbol{\Lambda}(L,q)\tilde{\mathbf{x}}_{t-1} + \boldsymbol{\eta}_t \quad (5)$$

where p is the lag length of global variables and q is the lag length of the feedback variables, $\tilde{\mathbf{x}}_t$, constructed by the country-specific domestic variables in the GVAR model. The first element of $\tilde{\mathbf{x}}_t$ is defined as

$$\tilde{x}_t^{(1)} = \sum_{i=1}^{N} \tilde{w}_i \, x_{it}^{(1)} \quad (6)$$

where $\tilde{w}_i$ represents a weight in order to construct these feedback variables.[51]

When we estimate the country-specific VARX* models and the global variable's VARX model, $\mathbf{x}_{it}^*$ and $\tilde{\mathbf{x}}_t$ are constructed directly from the data. However, at the time of dynamic analysis, such as calculating the impulse response functions, the values of $\mathbf{x}_{it}^*$ and $\tilde{\mathbf{x}}_t$ are calculated internally from the forecasted values of $\{\mathbf{x}_{jt}\}$ for j=1, …, N, which are obtained by solving the system of Equations (1), (2), (4), and (5). Thus, the GVAR model can describe the interactions of variables not only within a country, but also between countries.

As we report below, the variables included in the country-specific models and the global variable model are mostly integrated of order one. This implies that, if long-run equilibrium relationships exist among these variables, the VARX* models have their corresponding Vector Error Correction Model with exogenous variables (VECMX*) forms. If such long-run equilibrium relations are detected, they are imposed at the time of simulating the GIRFs.

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[49] Technically, we can use a different kind of w_ij for constructing the different variables. One possibility is to use capital flow data to construct financial weights for financial variables. See Galesi and Sgherri (2009), Eickmeier and Ng (2015) for empirical example, and Smith and Galesi (2014) for econometric specifications.

[50] Given the fact that China's emergence has drastically changed the trade flows after year 2001, it is more natural to use a time-varying trade weights. In the next stage, we will replace the time-constant weight with the time-varying weight.

[51] The weight $\tilde{w}_i$ is also not time-varying. In this study, $\tilde{w}_i$ is calculated from the 2009–2011 average of the GDP (in current international PPP) obtained from the World Development Indicators of the World Bank.

2.0 Estimation and testing

2.1 Data and a related specification issue

In the Real Sector GVAR study, we estimate 27 country-specific VARX* models and one commodity price VARX* model, at monthly frequency. Fourteen of them are Asian countries (Indonesia, Malaysia, Japan, Thailand, China, India, Korea, the Philippines, Singapore, Brunei, Cambodia, Lao PDR, Myanmar and Vietnam). For Financial Sector GVAR, as mentioned earlier, due to some data gaps, Brunei, Lao PDR and Myanmar are excluded from our sample dataset (and so only 24 country-specific VARX* models are estimated). Data are collected from various sources, including the International Financial Statistics by the IMF, Moody's and national authorities, which cover the period from January 2001 to December 2015 (for the Real Sector GVAR) and from January 2000 to December 2015 (for the Financial Sector GVAR).

For the Real Sector GVAR, the vector of domestic variables, $\mathbf{x}_{it}$, in the country-specific VARX* model includes at most six variables: industrial production y_{it}(mnemonic is ip); the headline consumer price index p_{it} (cpi); exports (in LCU, nominal) ex_{it} (exlcu); imports (in LCU, nominal) im_{it} (imlcu); the nominal effective exchange rate e_{it} (neer); and the short-term interest rate r_{it} (rshort).[52] Since y_{it}, e_{it} and r_{it} are missing for some countries, they are included when available. See Table 2.1 for details.

The domestic variable vector (for i=1,…,N) is $\mathbf{x}_{it} = (y_{it}, p_{it}, ex_{it}, im_{it}, e_{it}, r_{it})'$ where,

$$y_{it} = 100\times\log(\text{industrial production})$$

$$p_{it} = 100\times\log(\text{headline CPI})$$

$$ex_{it} = 100\times\log(\text{nominal export})$$

$$im_{it} = 100\times\log(\text{nominal import})$$

$$e_{it} = 100\times\log(\text{nominal effective exchange rate})$$

$$r_{it} = \text{short} - \text{term interest rate } (\%)$$

Before taking the logarithmic transformation, industrial production, headline CPI, export, import, and nominal effective exchange rates are all normalized so that the average value of the period 2009M01–2011M12 takes 100.

For Financial Sector GVAR, The vector of domestic variables, $\mathbf{x}_{it}$, in the country-specific VARX* model includes at most six variables: EDF of financial sector $edff_{it}$ (mnemonic is edff); EDF of corporate sector $edfc_{it}$ (edfc); the real short-term interest rate r_{it} (rint); the real equity price q_{it} (req); industrial production y_{it}(ip); and the real effective exchange rate e_{it} (reer).[53] When data is missing, they are excluded from the set of their domestic variables. See Table 2.2 for details.

The domestic variable vector (for i=1,…,N) is $\mathbf{x}_{it} = (edff_{it}, edfc_{it}, r_{it}, q_{it}, y_{it}, e_{it})'$ where

$$edff_{it} = \text{Moody's EDF of financial sector}$$

$$edfc_{it} = \text{Moody's EDF of corporate sector}$$

$$r_{it} = \text{real short} - \text{term interest rate } (\%)$$

$$q_{it} = 100\times\log(\text{equity price/CPI})$$

$$y_{it} = 100\times\log(\text{industrial production})$$

$$e_{it} = 100\times\log(\text{real effective exchange rate})$$

[52] Except for the short-term interest rate series, we have tested if the series contains seasonal variation. After adjusting the seasonality, we have detected the outliers. See Appendix for these procedures.

[53] For industrial production, we have adjusted the seasonality and the outliers.

The real short-term interest rates are calculated by subtracting the past annual rate of headline inflation from the nominal short-term rate (Galesi and Sgherri, 2009). For the U.S., we use the Wu-Xia index as the nominal short-term rate.

For the Real Sector GVAR, the set of foreign variables, $\mathbf{x}^*_{it}$, is constructed as defined by Equation (2). As discussed by Pesaran, Schuermann, and Weiner (2004) and Galesi and Lombardi (2009), due to a strong correlation between domestic and foreign-specific nominal effective exchange rates, the foreign-specific nominal effective exchange rates are excluded from the country-specific VARX* models. Moreover, by reflecting the fact that the U.S. is the only large open economy in the sample period, we assume that the foreign financial markets do not affect its economy. Thus, r^*_{it} is excluded from the U.S. model. See Table 3 for details.

For the Financial Sector GVAR, the set of foreign variables, $\mathbf{x}^*_{it}$, is constructed as defined by Equation (2). As discussed by Pesaran, Schuermann, and Weiner (2004) and Galesi and Lombardi (2009), due to a strong correlation between domestic and foreign-specific real effective exchange rates, the foreign-specific real effective exchange rates are excluded from the country-specific VARX* models. Moreover, by reflecting the fact that the U.S. is the only large open economy in the sample period, we assume that the foreign financial markets do not affect its economy. See Table 3.2 for details.

As for the global variables, $\boldsymbol{\omega}_t$, two commodity prices, log of crude oil price index p^O_t, and log of food price index p^F_t, are included in order to capture the influences from the international commodity market.

Table 1: List of Economies in Sample and their Abbreviations

Names	Abbreviation		Names	Abbreviation		Names	Abbreviation
BRAZIL	bra		JAPAN	jpn		PHILIPPINES	phl
INDONESIA	idn		MEXICO	mex		SINGAPORE	sgp
MALAYSIA	mys		SAUDI ARABIA	sau		TURKEY	tur
S. AFRICA	zaf		THAILAND	tha		NEW ZEALAND	nzl
U.K.	gbr		U.S.	usa		BRUNEI	brn
FRANCE	fra		CHINA	chn		CAMBODIA	khm
GERMANY	deu		INDIA	ind		LAO PDR	lao
ITALY	ita		KOREA	kor		MYANMAR	mmr
SPAIN	esp		AUSTRALIA	aus		VIETNAM	vnm

Table 2.1: List of Domestic Variables (Real Sector GVAR)

			INDUSTRIAL PRODUCTION	CPI	EXPORT (LCU)	IMPORT (LCU)	NOMINAL EER	SHORT TERM INTEREST RATE
	Names	Abbreviation	ip	cpi	exlcu	imlcu	neer	rshort
1	BRAZIL	bra	O	O	O	O	O	O
2	INDONESIA	idn	O	O	O	O	O	O
3	MALAYSIA	mys	O	O	O	O	O	O
4	S. AFRICA	zaf	O	O	O	O	O	O
5	U.K.	gbr	O	O	O	O	O	O
6	FRANCE	fra	O	O	O	O	O	O
7	GERMANY	deu	O	O	O	O	O	O
8	ITALY	ita	O	O	O	O	O	O
9	SPAIN	esp	O	O	O	O	O	O
10	JAPAN	jpn	O	O	O	O	O	O
11	MEXICO	mex	O	O	O	O	O	O
12	SAUDI ARABIA	sau	O	O	O	O	O	
13	THAILAND	tha	O	O	O	O	O	O
14	U.S.	usa	O	O	O	O	O	O
15	CHINA	chn	O	O	O	O	O	O
16	INDIA	ind	O	O	O	O	O	O
17	KOREA	kor	O	O	O	O	O	O
18	AUSTRALIA	aus	O	O	O	O	O	O
19	PHILIPPINES	phl	O	O	O	O	O	O
20	SINGAPORE	sgp	O	O	O	O	O	O
21	TURKEY	tur	O	O	O	O	O	O
22	NEW ZEALAND	nzl	O	O	O	O	O	O
23	BRUNEI	brn		O	O	O		
24	CAMBODIA	khm	O	O	O	O		
25	LAO PDR	lao		O	O	O		
26	MYANMAR	mmr		O	O	O		
27	VIETNAM	vnm	O	O	O	O		O

Table 2.2: List of Domestic Variables (Financial Sector GVAR)

			EDF OF FINANCIAL SECTOR	EDF OF CORPORATE SECTOR	REAL SHORT TERM INTEREST RATE	REAL EQUITY	INDUSTRIAL PRODUCTION	REAL EER
	Names	Abbreviation	edff	edfc	r	q	ip	reer
1	BRAZIL	bra	O	O	O	O	O	O
2	INDONESIA	idn	O	O	O	O	O	O
3	MALAYSIA	mys	O	O	O	O	O	O
4	S. AFRICA	zaf	O	O	O	O	O	O
5	U.K.	gbr	O	O	O	O	O	O
6	FRANCE	fra	O	O	O	O	O	O
7	GERMANY	deu	O	O	O	O	O	O
8	ITALY	ita	O	O	O	O	O	O
9	SPAIN	esp	O	O	O	O	O	O
10	JAPAN	jpn	O	O	O	O	O	O
11	MEXICO	mex	O	O	O	O	O	O
12	SAUDI ARABIA	sau					O	O
13	THAILAND	tha	O	O	O	O	O	O
14	U.S.	usa	O	O	O	O	O	O
15	CHINA	chn	O	O	O	O	O	O
16	INDIA	ind	O	O	O	O	O	O
17	KOREA	kor	O	O	O	O	O	O
18	AUSTRALIA	aus	O	O	O	O	O	O
19	PHILIPPINES	phl			O	O	O	O
20	SINGAPORE	sgp	O	O	O	O	O	O
21	TURKEY	tur	O	O	O	O	O	O
22	NEW ZEALAND	nzl	O	O	O	O	O	O
23	BRUNEI	brn	O	O	O	O	O	O
24	CAMBODIA	khm	O	O	O	O	O	O
25	LAO PDR	lao	O	O	O	O	O	O
26	MYANMAR	mmr					O	
27	VIETNAM	vnm			O		O	

Notes: A circle indicates that the data is available. A blank indicates that the corresponding variable is not available (either entirely or partially for the sample period), and is thus excluded from the dataset.

Table 3.1: Set of Variables used for the Real Sector GVAR Model

	Country-Specific VARX*			Commodity VAR	
	domestic $\mathbf{x}_{it}$	foreign $\mathbf{x}^{*}_{it}$	global $\boldsymbol{\omega}_{t}$	own $\boldsymbol{\omega}_{t}$	feedback $\tilde{\mathbf{x}}_{t}$
industrial production	y_{it}	y^{*}_{it}			$\tilde{y}_{t}$
consumer price index (headline)	p_{it}	p^{*}_{it}			
export (in LCU)	ex_{it}	ex^{*}_{it}			
import (in LCU)	im_{it}	im^{*}_{it}			
nominal effective exchange rate	e_{it}				
short-term interest rate	r_{it}	r^{*}_{it}			
oil price			p^{O}_{t}	p^{O}_{t}	
food price			p^{F}_{t}		p^{F}_{t}

Note: The foreign-specific short-term interest rate, r^{*}_{it}, is excluded from the U.S.'s VARX* model only.

Table 3.2: Set of Variables used for the Financial Sector GVAR Model

	Country-Specific VARX*			Commodity VAR	
	domestic $\mathbf{x}_{it}$	foreign $\mathbf{x}^{*}_{it}$	global $\boldsymbol{\omega}_{t}$	own $\boldsymbol{\omega}_{t}$	feedback $\tilde{\mathbf{x}}_{t}$
EDF of financial sector	$edff_{it}$	$edff^{*}_{it}$			
EDF of corporate sector	$edfc_{it}$	$edfc^{*}_{it}$			
real short-term interest rate	r_{it}	r^{*}_{it}			
real equity price	q_{it}	q^{*}_{it}			
industrial production	y_{it}	y^{*}_{it}			$\tilde{y}_{t}$
nominal effective exchange rate	e_{it}				
oil price			p^{O}_{t}	p^{O}_{t}	

Note: For the VARX* model of the U.S. economy, $edff^{*}_{it}$, $edff^{*}_{it}$, r^{*}_{it}, q^{*}_{it} are excluded.