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THE IMPACT OF GLOBAL ECONOMIC SHOCKS ON SOUTH AFRICA AMID TIME-VARYING TRADE LINKAGES

by

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Abstract

Trade of South Africa with the rest of the world has changed substantially since the mid-1990s. The United States (US), which used to be the main trading partner of South Africa, is now only the third largest trading partner of the country. South African trade with Germany, Japan and the United Kingdom (UK) are also lower. The key reason is the emergence of China in the world economy. South Africa did not trade with China before 1993, but from 2009 China became the main trading partner of the country. Globalisation and China's emergence have influenced the trade linkages of many other countries in the world. To incorporate the changes in global trade linkages, the foreign variables of all the models in the study are compiled with trade-weighted three-year moving average data.

The foremost objective of the thesis is to determine how the changes in trade linkages affect the transmission of economic shocks originating in the rest of the world on South Africa. The global vector autoregression (GVAR) approach is used since one of its advantages is the incorporation of global trade linkages, which facilitates the analysis of the transmission of shocks from one country to another.

As a GVAR model combines many individual country models, the study first estimates such a country-specific model for South Africa to determine whether it displays the expected impact of domestic shocks on the economy. This type of model is known as a vector error correction model (VECM) with domestic variables and weakly exogenous (X) foreign (*) variables, denoted by VECX*. The results from the VECX* for South Africa are in line with expectations, showing the effective transmission of monetary policy.

The study then examines the impact of international shocks on the South African economy with a GVAR model. The GVAR, which incorporates country-specific VECX* models for 33 countries, is solved for all 33 countries using global trade weight matrices at different dates. The results indicate that over time South Africa is much more vulnerable to GDP shocks to the Chinese economy, and less vulnerable to GDP shocks to the US economy. These trends are however not confined to South Africa, and as such highlights the increased risk to the South African economy and many other economies, should China experience slower GDP growth.

Finally, the thesis determines whether the forecasting performance of GVAR models is superior to that of a country-specific VECX* model. The study compares the out-of-sample forecasts of two key South African variables (real GDP and inflation) for five types of models: a VECX*, a customised small GVAR for South Africa, the more general 33-country GVAR, simple autoregressive models and random walk models. Better forecasts of both the GVAR models compared to the VECX* model at forecast horizons of more than four quarters show that, despite the complicated nature of the GVAR model with the inclusion of many countries and global trade linkages, the additional information is useful for forecasting domestic variables.

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LIST OF ABBREVIATIONS

AIC	Akaike information criterion
AR	Autoregressive
ARDL	Autoregressive distributed lag
BRIC	Brazil, Russia, India, China
BVAR	Bayesian vector autoregression
BVECM	Bayesian vector error correction model
CV	Cointegrating vector
DOTS	Direction of Trade Statistics
DSGE	Dynamic stochastic general equilibrium
FAVAR	Factor-augmented vector autoregression
FM	Factor Model
GAP	Relation between domestic output and foreign output
GIRF	Generalised impulse response function
GVAR	Global vector autoregression
IFS	International Financial Statistics
IMF	International Monetary Fund
LIR	Long-run interest rate rule (Fisher parity or modified Fisher parity)
LR	Log-likelihood ratio
MD	Money demand relationship
PP	Persistence profile
PPP	Purchasing power parity
PPP^A	Augmented purchasing power parity
QPM	Quarterly projection model
RMSFE	Root mean squared forecast error
RW	Random walk
SARB	South African Reserve Bank
SBC	Schwarz Bayesian criterion
UIP	Uncovered interest parity
VAR	Vector autoregression
VARX*	VAR augmented with weakly exogenous (X) foreign (*) variables
VECM	Vector error correction model
VECX*	VECM augmented with weakly exogenous (X) foreign (*) variables
WS-ADF	Weighted-Symmetric Augmented Dickey Fuller unit root test

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

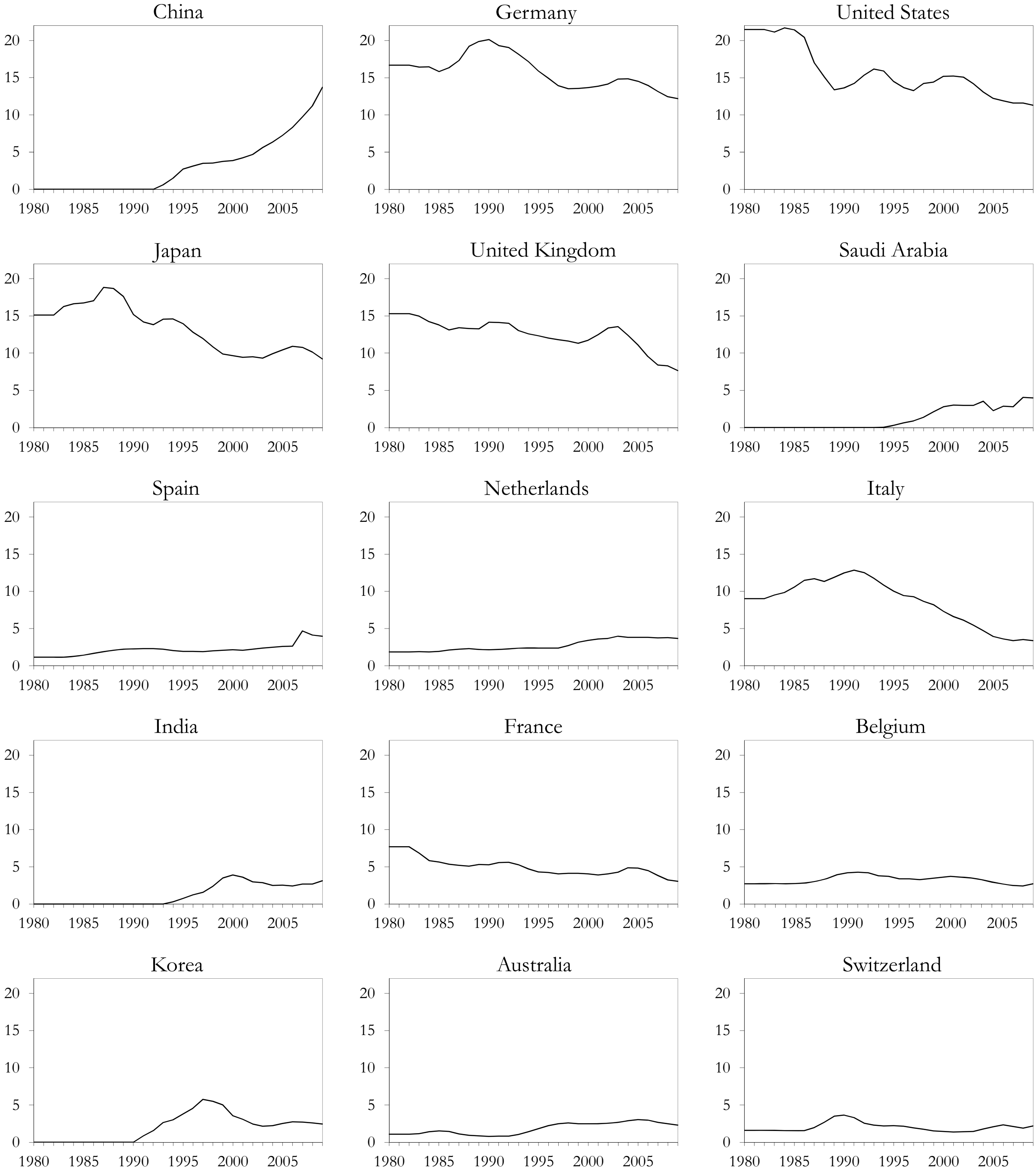
The global economy has been changing continuously over the past two decades. The forces driving the change are the rise of several large developing countries, especially the emergence of China, and the 'evolving network structure' between countries, with more complex supply chains and an increase in the tradable sector of the global economy (Spence, 2013). China has become a key world economy due to its high economic growth. Globally, China is now the second-largest economy, the leading exporter and the leading manufacturer (World Bank & Development Research Center of the State Council, 2013).

Small open economies are vulnerable to world events, and the continuous transition in the interconnectedness of the global economy has a major impact on the vulnerability of these economies. The trade linkages of South Africa with the rest of the world have changed considerably since the mid-1990s. The main reason for the change is China's emergence in the world economy. Since South Africa is a small open economy, economic shocks in the rest of the world are transmitted to South Africa, but due to the large increase in its connectedness to other developing economies, South Africa cannot focus only on the effect of shocks in advanced economies on the country. The linkages of South Africa with large and growing developing countries are central when analysing the economy.

The principal focus of this thesis is to determine how the large changes in trade linkages have affected the impact of economic shocks originating in the rest of the world on South Africa. The study uses the global vector autoregression (GVAR) approach as it incorporates global trade linkages, thereby enabling analysis of the transmission of shocks from one country to another. The foreign variables of all the models in the study are compiled with time-varying trade-weighted data to account for the significant changes in the trade linkages of South Africa and the rest of the world.

Trade between South Africa and China increased from zero before 1993 to a three-year moving average of 14 per cent in 2009. China became the largest trading partner of South Africa in 2009 (overtaking Germany's position). The United States (US) was the main trading partner of South Africa in the early 1980s, but it is now only the third largest trading partner of the country. Trade with the United Kingdom (UK), Japan and the other countries in the Euro area generally decreased over the past few decades. Figure 1.1 illustrates the substantial movements in the trade shares of the 15 most important trading partners of South Africa between 1980 and 2009[1].

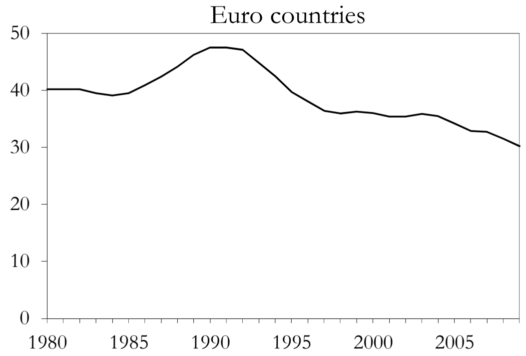
Figure 1.1 Three-year moving average trade weights (%) for 15 main trading partners



[1] The data are from the Global VAR (GVAR) Toolbox 1.1 dataset (Smith & Galesi, 2011).

Figure 1.2 shows the combined trade share of the eight Euro countries included in the model (Austria, Belgium, Finland, France, Germany, Italy, Netherlands and Spain) with South Africa from 1980 to 2009, highlighting the declining trade with these countries.

Figure 1.2 Three-year moving average trade weight (%) for Euro area



A GVAR combines individual country models. A vector error correction model (VECM) augmented with weakly exogenous (X) foreign (*) variables, denoted by VECX*, is constructed for each country in the GVAR before the system is solved. Thus, the first objective of the thesis is to develop a country-specific VECX* model for South Africa. To determine the effectiveness of the VECX*, the transmission of monetary policy is evaluated with the model. The foreign variables in the model are compiled with trade-weighted three-year moving average data for 32 countries, to account for the significant change in trade shares over time. The model is novel for South Africa, in two ways: it is the first VECX* developed to analyse monetary policy in the country and the first model that uses time-varying trade weights for the creation of the foreign series.

The 32 trading partners were chosen to align all the models in the thesis with the 33 countries (South Africa and 32 other countries) included in the GVAR Toolbox 1.1 dataset (Smith & Galesi, 2011). In addition, the sample for all the models were standardised to include data from 1979Q2 to 2009Q4 from the aforementioned database. In line with most of the GVAR literature and the motivation behind this thesis, the study uses trade shares to quantify the linkages between countries in the models. To account for indirect financial linkages, financial variables are included in the models. Since reliable data for the bilateral financial positions between all the countries in the GVAR are not available, all the foreign variables in the models are compiled using the trade weight matrix.

Table 1.1 shows the individual and total trade shares, based on data from the Direction of Trade Statistics (DOTS) of the International Monetary Fund (IMF, 2011), for trade between South Africa and the 32 trading partners considered for the models. These countries are responsible for 77 per cent of South Africa's average trade with all countries in the world from 2006 to 2010.

Table 1.1 Average trade shares of countries included in the model (2006 - 2010)

Country	Average trade share
China	10.58%
Germany	9.78%
US	8.82%
Japan	7.45%
UK	5.52%
Saudi Arabia	3.20%
Netherlands	2.90%
India	2.74%
Spain	2.55%
Italy	2.50%
France	2.48%
Belgium	1.91%
Korea	1.89%
Australia	1.82%
Switzerland	1.64%
Brazil	1.43%
Thailand	1.39%
Malaysia	1.09%
Sweden	1.08%
Singapore	0.97%
Argentina	0.91%
Canada	0.81%
Turkey	0.68%
Indonesia	0.67%
Austria	0.57%
Finland	0.50%
Mexico	0.36%
Norway	0.24%
New Zealand	0.17%
Philippines	0.13%
Chile	0.12%
Peru	0.05%
Total	**76.95%**
Euro countries	23.20%

Source: Calculated from Direction of Trade Statistics (DOTS) of the IMF (2011).

The second and main objective of the thesis is to develop a GVAR to investigate the transmission of economic shocks that originate in China and the US respectively on the South

African economy. The GVAR includes country-specific VECX* models for each of the 33 countries (South Africa and the 32 countries listed in Table 1.1). The country-specific foreign variables for the VECX* models are assembled with time-varying trade-weighted data to account for changes in international trade linkages. The GVAR is solved for all the countries as a whole using global trade weight matrices at different dates to compare the impact of economic shocks over time. *A priori* expectations are that the significant change in South Africa's trade patterns over the past two decades should affect the impact of shocks in the rest of the world on the country, since it is a small open economy. The current study is one of the first GVAR study for the South African economy.

The third and last objective of the thesis is to determine whether the GVAR approach provides better forecasts of key South African variables than a VECX* for South Africa. Both a small GVAR model and a large GVAR model are considered to determine the most appropriate GVAR for forecasting South African variables. The recursive out-of-sample forecasts for South African GDP and inflation are compared for five types of models: a general 33-country (large) GVAR, a customised small GVAR for South Africa, a VECX* for South Africa, autoregressive (AR) models and random walk (RW) models.

1.2. OUTLINE OF STUDY

The next chapter, Chapter 2, addresses the first objective of the thesis. It describes the development of a VECX* for South Africa, which is used to analyse the transmission of monetary policy in South Africa.

The main objective of this thesis is to determine how the impact of economic shocks to China and the US respectively on South Africa has changed since 1995, with the use of a GVAR model with time-varying weights. Chapter 3 contains the model and results.

The investigation of the forecast performance of GVAR models is the final objective of the study. In Chapter 4, the out-of-sample forecasts of key South African variables for two distinct GVAR models, a VECX* for South Africa and two standard benchmark models are compared.

The final chapter, Chapter 5, concludes the overall study, with summaries of the main contributions and findings, and it provides several areas of further research that could follow the research in this thesis.

CHAPTER 2

MONETARY POLICY AND INFLATION IN SOUTH AFRICA: A VECM AUGMENTED WITH FOREIGN VARIABLES[2]

2.1. INTRODUCTION

South Africa adopted inflation targeting as its primary tool of monetary policy in 2000. To date the South African Reserve Bank (SARB) remains committed to inflation targeting to ensure long-run price stability. In a letter from Finance Minister Pravin Gordhan to SARB Governor Gill Marcus, dated 16 February 2010, Minister Gordhan stated that 'the Bank should continue to pursue a target of 3 to 6 per cent for headline CPI inflation' (Gordhan, 2010). He highlighted the importance of maintaining low inflation – that it supports sustainable growth and employment, and that it protects the living standards of people in the country.

An investigation to determine the effectiveness of monetary policy transmission is thus still important to ensure appropriate policy actions in South Africa. It is not sufficient to know only the direction of change in variables following a change in monetary policy (Bain & Howells, 2003). It is also important that policy makers take into account the time lag between a change in the official interest rate (the repo rate) and its impact on aggregate output and inflation, as well as the magnitude of changes in output and inflation. Mishkin (1995) names these elements the 'timing and effect' of monetary policies on the economy.

Time lags tend to differ from country to country due to differences in economic and financial market structures (Casteleijn, 2001). Bain and Howells (2003) note that for industrialised countries, the lag between a change in the official interest rate and its full impact on demand and production is normally about 12 months. The lag between the interest rate change and the full impact on inflation is 24 months, thus a further 12 months. Research by the SARB, performed more than a decade ago, confirmed these time lags for South Africa (Smal & De Jager, 2001). As far as known, the study by Smal and De Jager (2001) is the only complete assessment of the transmission of monetary policy for South Africa. The authors do not provide details to replicate their small macroeconometric model.

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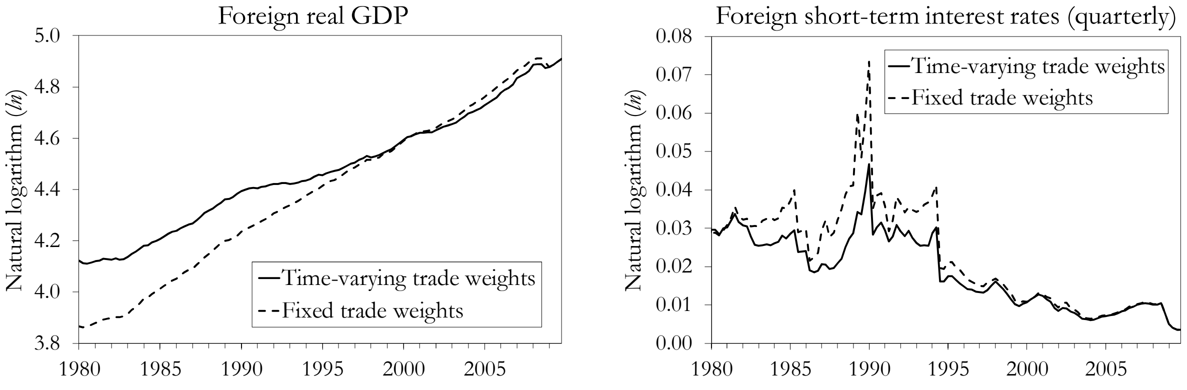
[2]This chapter is a modified version of Economic Research Southern Africa (ERSA) working paper 316.

The objective of this chapter is to develop a suitable topical model for analysing the transmission of monetary policy changes to inflation in South Africa. The model must include a foreign component, since South Africa is a small open economy. Due to substantial changes in the trade shares of South Africa's key trading partners, as highlighted in Chapter 1, this study argues that the incorporation of foreign variables created using time-varying trade-weighted data is more accurate. Previous macroeconometric models for South African use either US data as a proxy for the rest of the world or they use fixed trade weights to weigh data of the main trading partners.

To account for the significant changes in trade shares, time-varying trade weights and data for 32 countries are used to create the foreign variables in the model for South Africa. Figure 2.1 highlights the difference between foreign variables calculated with time-varying trade weights (three-year moving averages) and those calculated with fixed trade weights (average trade weights from 2007 to 2009). Fixed trade-weighted foreign variables do not incorporate the substantial change in trade shares between 1980 and 2009. As a result, these variables display larger variations than the time-varying trade-weighted foreign variables. For example, if foreign real GDP is calculated as the real GDP of the foreign countries weighted with the average trade shares of these countries with South Africa between 2007 and 2009, China's GDP is given a sizeable weight throughout the sample although South Africa did not trade with China before 1993. Since the GDP of China grew at a fast pace off a low base, the use of fixed trade weights results in a foreign real GDP variable that grows faster off a lower base than the variable that is created using time-varying trade weights, as is evident in the first graph of Figure 2.1.

Figure 2.1 Foreign variable comparison - Time-varying trade weights versus fixed trade weights



This chapter specifies the development of a structural VECM with weakly exogenous (X) foreign (*) variables (Pesaran, Shin & Smith, 2000; Pesaran & Shin, 2002; Garratt, Lee, Pesaran & Shin, 2003; Garratt, Lee, Pesaran & Shin, 2006). This type of model, which is suitable for a small open economy such as South Africa, is referred to by VECX*. Applications of VECX* in the literature include models for the UK (Garratt *et al.*, 2003), Thailand (Akusuwan, 2005), Indonesia (Affandi, 2007) and Switzerland (Assenmacher-Wesche & Pesaran, 2008; 2009).

To my knowledge, this is the first VECX* developed to analyse the transmission of monetary policy in South Africa. De Wet, Van Eyden and Gupta (2009) developed a VECM model for South Africa using part of the framework suggested in earlier GVAR studies. Their model is not comparable to the VECX* models listed above, since it has a different purpose (it investigates portfolio risk) and it does not utilise the Garratt *et al.* (2006) framework.

The next section provides more information on the literature consulted, while Section 2.3 briefly outlines the VECX* methodology. Sections 2.4, 2.5 and 2.6 respectively provide information on the data, analysis of the data and the VECX* model results. Section 2.7 concludes the chapter.

2.2. LITERATURE REVIEW

Section 2.2.1 reviews the literature related to VECX* models. Section 2.2.2 describes all the channels of the monetary transmission mechanism, since this study investigates some of the channels of the transmission mechanism. A summary of the models of the SARB, especially the study of Smal and De Jager (2001) that investigates the full monetary transmission mechanism, is included in Section 2.2.3.

2.2.1 VECX* models

VECX* models are also classified as cointegrating VARX or cointegrating VARX* models (Affandi, 2007; Garratt *et al.*, 2006). Pesaran *et al.* (2000), Pesaran and Shin (2002) and Garratt *et al.* (2003) introduced and further developed these models. A detailed explanation of the methodology is provided in Garratt *et al.* (2006). Pesaran *et al.* (2000) explain that the models are particularly suitable for small open economies due to the handling of foreign variables as weakly exogenous. Pesaran and Smith (2006) further illustrate that this type of model can be derived as the solution to an open macro economy New Keynesian dynamic stochastic general equilibrium (DSGE) model, thereby underpinning the long-run relations considered in the VECX* model.

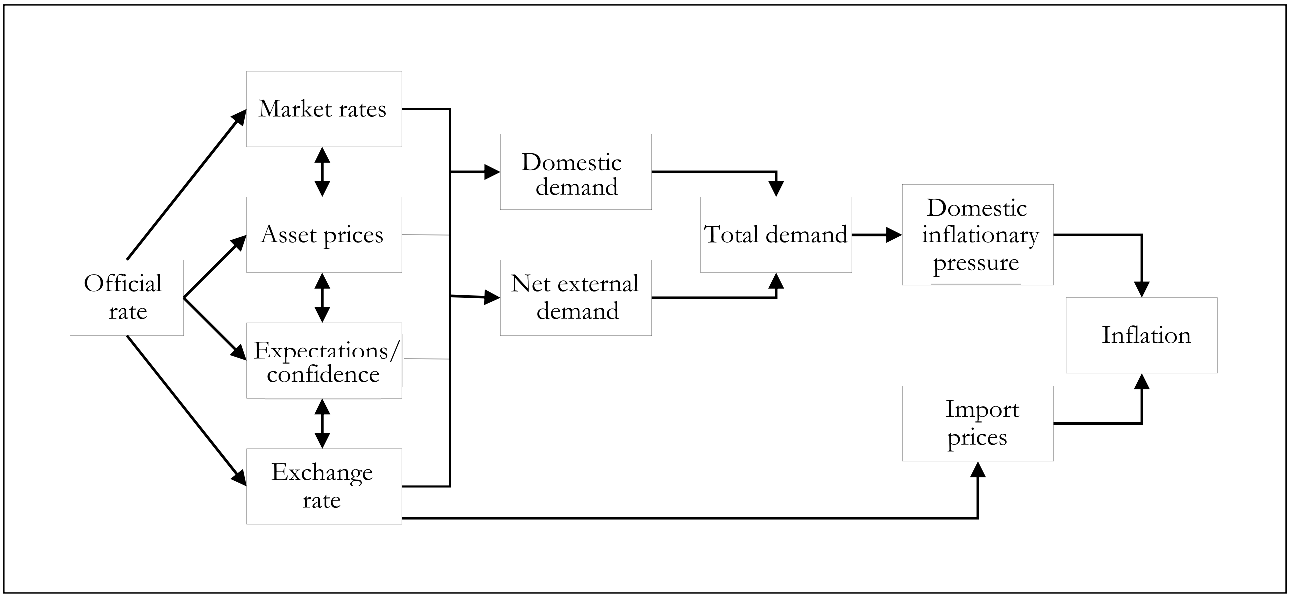
Therefore, the first advantage of using a VECX* approach for South Africa is that the model accounts for long-run theoretical relations and short-run properties, which are both important in the analysis of the impact of monetary policy shocks on the system. Second, the inclusion of weakly exogenous foreign variables, which is relevant for a small open economy such as South Africa, is possible in a VECX* model. Another advantage of developing a VECX* for South Africa is that it can be incorporated directly into a GVAR model, where all the foreign variables are determined endogenously. Pesaran, Schuermann and Weiner (2004) proposed the GVAR framework.

The first VECX* model was developed by Garratt *et al.* (2003) for the UK economy. Further VECX* models followed for Thailand (Akusuwan, 2005), Indonesia (Affandi, 2007) and Switzerland (Assenmacher-Wesche & Pesaran, 2008; 2009). The countries considered in these studies are small open economies such as South Africa. In addition, the UK and Thailand are full-fledged inflation-targeting countries like South Africa. Indonesia is categorised as an inflation-targeting 'lite' country, while Switzerland follows implicit inflation targeting. Due to the similarities, all the above studies are relevant to the VECX* model for South Africa developed here. Since South Africa is an emerging market economy, particular attention is paid to the models of Thailand and Indonesia. Each of the previous VECX* studies effectively explores the monetary policy transmission process in the country considered, which is the objective of this study. In addition, the models are successful in forecasting inflation.

2.2.2 The monetary transmission mechanism

Bain and Howells (2003) define the transmission mechanism of monetary policy as the 'series of links between the monetary policy change and the changes in output, employment and inflation'. This study considers a monetary policy change as a change in the official short-term interest rate at which the central bank lends money to the banking sector. This transmission process is summarised in Figure 2.2.

Figure 2.2 The transmission mechanism of monetary policy



Source: Adapted from Bank of England (1999).

Figure 2.2 illustrates the various transmission mechanisms, or channels, through which changes in monetary policy affect the real economy and inflation in a country. Mishkin (1995) uses the following categories to describe the transmission mechanisms: the interest rate channel, the exchange rate channel, other asset price channels and the credit channel. These channels are discussed below, for the most part using the categories chosen by Mishkin (1995) and the notation utilised by Smal and De Jager (2001).

Schematically the *interest rate channel* can be represented as follows:

$\downarrow$official rate $\rightarrow$ $\downarrow$other interest rates $\rightarrow$ ($\uparrow$I, $\uparrow$C) $\rightarrow$ $\uparrow$Y,

where $\downarrow$official rate shows an expansionary monetary policy through a decrease in the official short-term interest rate at which the central bank lends money to the banking sector. This causes other interest rates in the economy to decrease, which in turn increase fixed capital formation (I) and consumption spending (C), resulting in an increase in real economic output (Y).

Changes in monetary policy also affect the real economy through the effect of exchange rate (ER) changes on net exports (NX). Lower domestic interest rates in comparison to interest rates in foreign countries depreciate the domestic currency, leading to an increase in net exports and thus in real economic activity. The *exchange rate channel* can be presented as follows:

↓official rate → ↓other interest rates → ↓ER → ↑NX → ↑Y

Mishkin (1995) furthermore shows how the monetary transmission mechanism works through other relative asset prices and real wealth. Schematic illustrations of the two *other asset price channels* are:

↓official rate → ↑equity prices → ↑I → ↑Y
↓official rate → ↑prices of equity, property and land → ↑wealth → ↑C → ↑Y

The first of the above channels illustrates the transmission mechanism through other relative asset prices, where lower interest rates would increase equity prices and the attractiveness of investment spending according to Tobin's *q* theory of investment (in Mishkin, 1995). The second channel shows the transmission mechanism through wealth effects on consumption, where the prices of previously acquired assets would increase due to lower interest rates, thereby increasing the wealth and consumption spending of the asset holders.

The final channel is the *credit channel*. Mishkin (1995) separates the credit channel, which incorporates problems with asymmetric information and the expensive enforcement of contracts, into the bank-lending channel and balance-sheet channel. The *bank-lending channel* illustrates how a change in the official rate would change bank reserves and bank deposits, and hence bank loans to households and small firms as well as aggregate economic activity, in the opposite direction. This can be illustrated as follows:

↓official rate → (↑bank reserves, ↑bank deposits) → ↑bank loans → (↑I, ↑C) → ↑Y

The *balance-sheet channel* specifically deals with the net worth of households and firms. As shown with the other asset price channels, an expansionary monetary policy causes an increase in equity prices, thereby increasing the net worth of households and firms. In addition, lower interest rates improve the cash flow position of households and businesses, as a result further increasing their net worth. Adverse selection and moral hazard problems are lower and lending increases, allowing higher consumption and investment spending. The schematic representation of the balance-sheet channel is:

↓official rate → ↑equity prices, ↑cash flow → ↓adverse selection, ↓moral hazard → ↑lending → (↑I, ↑C) → ↑Y

Understandably, these conventional channels of the monetary transmission mechanism have been scrutinised following the global financial crisis. The consensus is that the conventional monetary policy channels understate the importance of the credit channel. The credit channel has long been highlighted as important in the transmission of monetary policy (Bernanke & Gertler, 1995). Boivin, Kiley and Mishkin (2000), in research on the evolution of the monetary transmission mechanism, divide the transmission channels into neoclassical channels and non-neoclassical channels. The neoclassical channels transmit monetary policy through the interest rate, wealth effects, intertemporal substitution and exchange rate effects. The non-neoclassical channels are regulation-induced credit effects, bank-based channels and the balance-sheet channel. These neo-classical mechanisms are known as the 'credit view', incorporating the effects of financial market imperfections and asset prices. The 'credit view' was not sufficiently accounted for before the financial crisis. Du Plessis (2012) argue that a return to central bank balance sheet policy, and thus central bank reserves, could be an influential and permanent tool to impact on the transmission of interest rate policy, whilst ensuring long-run financial stability.

2.2.3 SARB macroeconometric models

The VECX* model for South Africa and its inclusion into a GVAR model could be a useful addition to the suite of econometric models of the SARB.

The models currently used by the SARB include a core model (SARB, 2007), a small-scale macroeconometric model, VAR models, VECMs, Phillips-curve models, indicator models and structural VAR models (Casteleijn, 2001). More recently, the SARB developed quarterly projection models (QPMs) and DSGE models, including a steady state QPM for the country (De Jager, 2007), a New Keynesian DSGE model for South Africa (Steinbach, Mathuloe & Smit, 2009) and a Small Open Economy New Keynesian DSGE-VAR (SOENKDSGE-VAR) model for South Africa (Gupta & Steinbach, 2013). The SARB draws on these models for various purposes, including forecasting and simulations. However, none of these models includes time-varying trade-weighted foreign variables. Sections 1.1 and 2.1 showed that the incorporation of time-varying weights in an open economy model for South Africa (as in this VECX* model) is important due to substantial changes in the trade weights of South Africa's main trading partners over time.

In the context of the aim of this study to investigate the impact of monetary policy shocks on inflation in South Africa, to my knowledge, the only complete published investigation of the monetary transmission mechanism in South Africa is by Smal and De Jager (2001) from the SARB. The authors analyse the monetary transmission mechanism in South Africa with a small-scale macroeconometric model. They discuss monetary policy in the country since the 1980s, before investigating the various transmission mechanisms, or channels, through which changes in monetary policy affect the real economy and inflation in a country. The channels, discussed in Section 2.2.2, are the interest rate channel, other asset price channels (exchange rate and equity prices) and the credit channel (bank-lending channel and balance-sheet channel). Their model incorporates these channels to explore the lags involved in the transmission of monetary policy in South Africa. The authors provide no specific details of the model used, but they do clarify the two scenarios used to shock the system to determine the lags involved. These scenarios include an increase in the repo rate (providing for the real exchange rate to be affected by the interest rate differential and purchasing power parity) and a change in the repo rate with a Taylor-type monetary policy reaction function added to the model (which will further allow the repo rate to adjust to domestic output and inflation). Smal and De Jager (2001) confirm the time lag between a change in the official interest rate and the full impact on demand and production, which is real economic activity, as approximately 12 months. The authors verify the lag between a change in monetary policy and the full impact on domestic inflation as approximately 24 months, thus a further 12 months, but they caution that the lags are dependent on the prevailing factors.

For the SARB, the core model ['a medium-sized Type II hybrid model', (2007)], the QPM model (De Jager, 2007) and the New Keynesian DSGE model (Steinbach *et al.*, 2009) all include monetary policy transmission channels. The authors note that the models' responses to shocks illustrate the correct functioning of the monetary transmission mechanism in South Africa, but they do not provide a clear indication of the time lags and magnitude of changes following a monetary policy shock.

The model in this study accounts for the traditional interest rate channel and the exchange rate channel of the monetary transmission mechanism, using the Mishkin (1995, 2004) classification. According to the traditional interest rate channel, expansionary monetary policy (a decrease in the official rate) will cause other interest rates to decrease. Lower interest rates will increase consumption and fixed investment. As a result, real output will increase. According to the exchange rate channel, expansionary monetary policy will lower domestic interest rates compared to foreign interest rates. The exchange rate will depreciate, leading to higher net exports and thus higher real output.

This research thus adds to the literature by developing a VECX* for South Africa that includes time-varying trade-weighted foreign variables to account for the substantial change in the trade shares of the key trading partners over time. In addition, it provides a more recent view of the transmission of monetary policy in South Africa.

2.3. VECX* METHODOLOGY

The VECX* approach is documented in Garratt *et al.* (2006). This section provides a brief summary of the methodology.

The VECX* model can be represented by

$$\Delta \mathbf{y}_t = -\mathbf{\Pi}_y \mathbf{z}_{t-1} + \mathbf{\Lambda} \Delta \mathbf{x}_t + \sum_{i=1}^{p-1} \mathbf{\Psi}_i \Delta \mathbf{z}_{t-i} + \mathbf{c}_0 + \mathbf{c}_1 t + \mathbf{\nu}_t, \tag{2.1}$$

with the marginal equations for the weakly exogenous variables identified as

$$\Delta \mathbf{x}_t = \sum_{i=1}^{p-1} \mathbf{\Gamma}_{xi} \Delta \mathbf{z}_{t-i} + \mathbf{a}_{x0} + \mathbf{u}_{xt}. \tag{2.2}$$

A vector of endogenous and exogenous $I(1)$ variables, $\mathbf{z}_t$, can be written as $\mathbf{z}_t = (\mathbf{y}'_t, \mathbf{x}'_t)'$, with $\mathbf{y}_t$ a vector of endogenous $I(1)$ variables (the domestic variables) and $\mathbf{x}_t$ a vector of exogenous $I(1)$ variables (the foreign variables). Assume now that $\mathbf{x}_t$ is weakly exogenous (also known as long-run forcing for $\mathbf{y}_t$) in the long-run multiplier matrix $\mathbf{\Pi}$ of a normal VECM.

The definition of weakly exogenous variables in the VECX* framework differs from that of Hendry and Richard (1983), who refer to weakly exogenous explanatory variables as regressors that are uncorrelated with the stochastic error term. The weak exogeneity assumption in the VECX* model corresponds to $\mathbf{\Pi}_x = 0$, where $\mathbf{\Pi}$ is separated as $\mathbf{\Pi}' = (\mathbf{\Pi}'_y, \mathbf{\Pi}'_x)$. Thus, the long-run multiplier matrix of a VECX* model is $\mathbf{\Pi}_y$, as indicated in equation (2.1), while the marginal or sub-system VECM model for the weakly exogenous foreign variables does not contain the cointegrating vectors of the overall VECX* model since $\mathbf{\Pi}_x = 0$ (Pesaran *et al.*, 2000). Equation (2.2) shows the marginal equations for the foreign variables. Weak exogeneity therefore implies that domestic variables do not affect foreign variables in the long term, since the domestic economy is small and open. This assumption is necessary for modelling South Africa, since it has a small and open economy.

The deterministic components include an unrestricted intercept and a restricted trend. A trend is included when the variables contain deterministic trend components, which is mostly the case with macroeconomic variables. The trend coefficient is restricted to lie within the cointegrating space, since an unrestricted trend could potentially cause quadratic trends in the variables in levels as the model is expected to contain a unit root.

2.4. DATA

The VECX* model for South Africa incorporates quarterly domestic and time-varying trade-weighted foreign data from 1979Q2 to 2009Q4. Table 2.1 lists the variables. Variables without an assigned type are not included in the final VECX* model, but they are used for calculations and for data analysis. For clarity, Section A.1 in Appendix A provides further information about the definitions, calculations and sources of the data, especially note the discussion on construction of the real effective exchange rate variable.

Table 2.1 Variables

Variable	Description	Type
y	*ln* real GDP	Endogenous $I(1)$
π	Quarterly inflation rate: first difference of *ln* CPI	Endogenous $I(0)$
r	0.25**ln*(1+repo rate/100)	Endogenous $I(0)$
e	*ln* nominal effective exchange rate	
p	*ln* CPI	
ep	*ln* real effective exchange rate = $e - p$	Endogenous $I(1)$
lr	0.25**ln*(1+long-term interest rate/100)	Endogenous $I(1)$
$m3$	*ln* real M3	
y^*	*ln* foreign real GDP	Exogenous $I(1)$
p^*	*ln* foreign CPI	Exogenous $I(1)$
r^*	0.25**ln*(1+foreign short-term interest rate/100))	Exogenous $I(1)$
p^{oil}	*ln* oil price	Exogenous $I(1)$
$y - y^*$	Ratio of *ln* real GDP to *ln* foreign real GDP	
$p - p^*$	Ratio of *ln* CPI to *ln* foreign CPI	

d92	Dummy variable: 1 from 1992Q1 onwards	Deterministic

The real exchange rate definition used here differs from the usual definition of $(e - p - p^{*})$. The definition used in this thesis is the natural logarithm of the nominal exchange rate deflated by the natural logarithm of the domestic CPI, or $(e - p)$. This term is standard to the GVAR literature (for example Pesaran *et al.*, 2004; Pesaran & Smith, 2006; Affandi, 2007; Dées, Di Mauro, Pesaran & Smith, 2007a; Eickmeier & Ng, 2011; Cesa-Bianchi, Pesaran, Rebucci & Xu, 2012; Assenmacher-Wesche & Geismann, 2013). By using $(e - p)$ to calculate the real exchange rate, it is possible to separate the domestic (endogenous) variables from the foreign (weakly exogenous) variables, which is important in VECX* and GVAR models.

The dummy variable (*d92*) accommodates the structural change in South Africa in the early 1990s. Various other dummy variables (denoting structural breaks in respectively 1990, 1991, 1993 and 1994) were considered, but *d92* (denoting a structural break in 1992) was more significant. The structural break makes sense, since it is halfway between the release of Nelson Mandela in 1990 and the political transitions in 1994. The variable is also in line with the onset of globalisation and the increased openness of the South African economy due to the termination of economic sanctions against the country.

Interest rates are adjusted to be comparable with the quarterly inflation rate. For the creation of the foreign variables, that are all assumed to be weakly exogenous, the three-year moving average trade weights of South Africa with each of the other 32 counties in the GVAR dataset were calculated from the annual trade data (average of exports and imports, c.i.f.[3]) between 1980 and 2009. Time-varying trade shares were used to weigh each variable for all the countries. The summation of the weighted country data provided each specific foreign variable. All the variables are used in natural logarithmic form. Unit root tests indicate that the variables in the model are generally *I*(1). Section A.2 in Appendix A includes the results of the unit root tests.

Table A.1 in Appendix A shows the data sources for the variables. Except for broad money supply (M3) for South Africa, the data are from the GVAR Toolbox 1.1 dataset (Smith & Galesi, 2011), which includes data for 33 countries (South Africa and 32 other countries) accounting for around 90 per cent of world output. Comprehensive information about the data sources and the methods of calculation for the GVAR Toolbox 1.1 database is included in Technical Appendix B

[3] Cost, insurance and freight.

of the User Guide compiled by Smith and Galesi (2011). M3 for South Africa is from the International Financial Statistics (IFS) of the International Monetary Fund (IMF).

Figure 2.3 presents graphs of all the variables in Table 2.1.

Figure 2.3 Graphs of variables

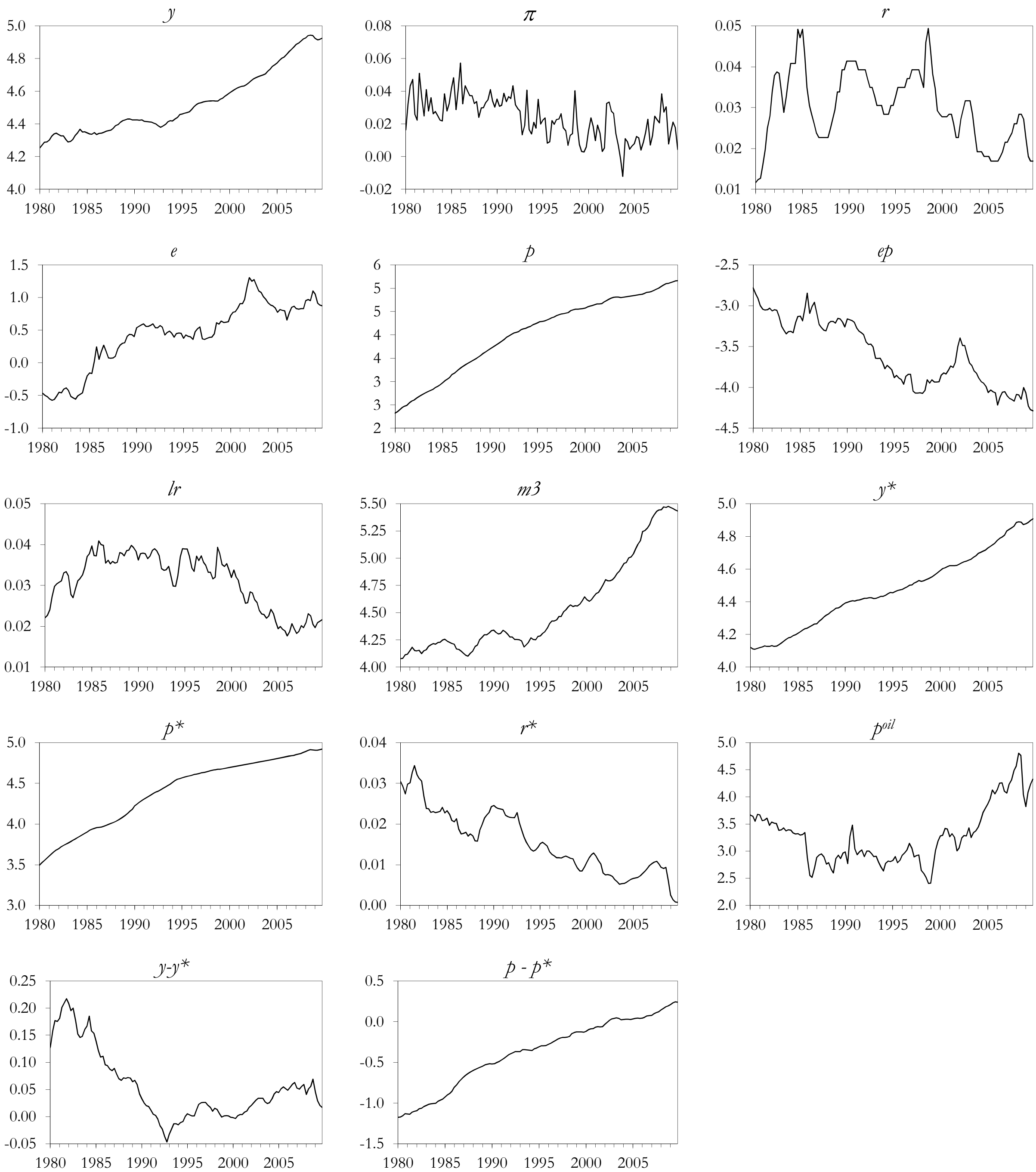


Table 2.2 contains the simple correlation coefficients between all the variables in Table 2.1. However, since almost all the variables are non-stationary, the majority of the correlation

coefficients in Table 2.2 are potentially spurious. Table 2.3 thus shows the correlation coefficients between the variables, that are included in the final VECX* model, in their stationary form. With the exception of the domestic inflation and repo rates (respectively π and r), which are both stationary, the variables are in their first differenced form to render them stationary.

Table 2.2 Simple correlation coefficients

	y	π	r	e	p	ep	lr	$m3$	y^*	p^*	r^*	p^{oil}	$y\text{-}y^*$	$p\text{-}p^*$
y	1													
π	-0.54*	1												
r	-0.32*	0.24*	1											
e	0.80*	-0.48*	-0.12	1										
p	0.89*	-0.61*	-0.12	0.94*	1									
ep	-0.84*	0.66*	0.10	-0.70*	-0.91*	1								
lr	-0.65*	0.44*	0.72*	-0.29*	-0.37*	0.40*	1							
$m3$	0.99*	-0.51*	-0.35*	0.73*	0.82*	-0.79*	-0.72*	1						
y^*	0.97*	-0.58*	-0.26*	0.90*	0.97*	-0.88*	-0.54*	0.93*	1					
p^*	0.87*	-0.62*	-0.08	0.92*	0.99*	-0.92*	-0.34*	0.80*	0.95*	1				
r^*	-0.84*	0.64*	0.28*	-0.84*	-0.91*	0.84*	0.45*	-0.79*	-0.89*	-0.90*	1			
p^{oil}	0.61*	-0.15	-0.49*	0.14	0.23*	-0.29*	-0.79*	0.69*	0.44*	0.21*	-0.21*	1		
$y\text{-}y^*$	-0.40*	0.41*	-0.06	-0.77*	-0.75*	0.60*	-0.08	-0.31*	-0.62*	-0.76*	0.63*	0.28*	1	
$p\text{-}p^*$	0.90*	-0.60*	-0.16*	0.95*	0.99*	-0.89*	-0.40*	0.83*	0.97*	0.99*	-0.92*	0.25*	-0.75*	1

An asterisk denotes significance at the 10% level.

Table 2.3 Simple correlation coefficients for variables in their stationary form

	$D(y)$	π	r	$D(ep)$	$D(lr)$	$D(y^*)$	$D(p^*)$	$D(r^*)$	$D(p^{oil})$
$D(y)$	1								
π	-0.24*	1							
r	-0.42*	0.25*	1						
$D(ep)$	0.14	-0.08	0.18*	1					
$D(lr)$	0.20*	0.27*	0.06	0.22*	1				
$D(y^*)$	0.24*	-0.12	-0.13	0.09	0.10	1			
$D(p^*)$	-0.01	0.55*	0.12	-0.08	0.17*	-0.17*	1		
$D(r^*)$	0.32*	0.09	-0.18*	-0.12	0.15	0.35*	0.29*	1	
$D(p^{oil})$	0.25*	-0.02	-0.12	-0.09	0.15	0.34*	0.07	0.28*	1

An asterisk denotes significance at the 10% level.

2.5. DATA ANALYSIS

In the remainder of the study in this chapter, the modelling approach used by Assenmacher-Wesche and Pesaran (2009) in their development of a VECX* model for Switzerland is followed.

The long-run economic relations considered for South Africa are the purchasing power parity (PPP), the uncovered interest parity that relates domestic and foreign interest rates (UIP), the Fisher parity that links the domestic interest rate to domestic inflation (long-run interest rate rule or LIR), a money demand relationship (MD) and a connection between domestic and foreign output (GAP). These long-run relations, based on the derived long-run equilibrium relationships detailed in Garratt *et al.* (2006), are investigated in the VECX* literature discussed in Section 2.2.1. I therefore decided to investigate the same relations for South Africa for comparative purposes.

Table 2.4 shows which of these five long-run relations hold in the cases of Switzerland (Assenmacher-Wesche & Pesaran, 2009), Thailand (Akusuwan, 2005) and Indonesia (Affandi, 2007), based on the autoregressive distributed lag (ARDL) or bounds testing approach to cointegration (Pesaran & Shin, 1999; Pesaran, Shin & Smith, 2001). One of the advantages of the ARDL approach is that it is not necessary to know whether variables are *I*(0) or *I*(1), that is stationary or non-stationary.

Table 2.4 Long-term economic relationships in previous VECX* studies[4]

	Switzerland	Thailand	Indonesia
PPP[a]	✓	×	✓
UIP[b]	✓	✓	✓
LIR[c]	✓	✓	✓
MD[d]	✓	✓	×
GAP[e]	✓	×	×

[a] PPP: Purchasing power parity ($p - p^* - e$) or PPP[A]: Augmented purchasing power parity ($e - (p - p^*) - \beta_1(y - y^*)$)

[b] UIP: Uncovered interest parity ($r - r^*$)

[c] LIR: Fisher parity ($r - \pi$) or Modified Fisher parity ($r - \beta_2 \pi$)

[d] MD: Money demand relationship ($m - \beta_3 y - \beta_4 r$)

[e] GAP: Relation between domestic output and foreign output ($y - y^*$)

[4] The following relationships differ from the conventional forms: the Fisher parity (LIR) does not include expected inflation and the uncovered interest parity (UIP) does not include the expected depreciation in the exchange rate. Garratt *et al.* (2006) describe the convergence to the long-run economic relationships used in this study.

The domestic variables needed to test these relationships are the nominal effective exchange rate (e), prices (p), the repo rate (r), the quarterly inflation rate (π), real M3 ($m3$) and real output (y). The foreign variables used are foreign prices (p^*), foreign real output (y^*) and the foreign short-term interest rate (r^*).

First, the potential long-term relations are investigated graphically. Theoretically, the PPP suggests that domestic and foreign prices calculated in the same currency will be in equilibrium in the long term due to global trade. Due to the large correlation between the exchange rate (e) and the output gap ($y - y^*$), observed in Table 2.2 in Section 2.4, both PPP ($p - p^* - e$) and PPP[A], augmented purchasing power parity, ($e - (p - p^*) - \beta_1(y - y^*)$), are explored.

Figure 2.4 and Figure 2.5 show the movement in exchange rates against the ratio of domestic and foreign prices and the ratio of domestic and foreign output respectively, both in levels and in first differences. The exchange rate and the ratio of domestic to foreign prices have the same trend in the long term, suggesting that the PPP may hold for South Africa. The negative relationship between the exchange rate and the ratio of domestic to foreign output is only evident up to 2000. It is therefore not clear whether the augmented PPP will be relevant for South Africa.

Figure 2.4 Exchange rate and ratio of domestic to foreign prices

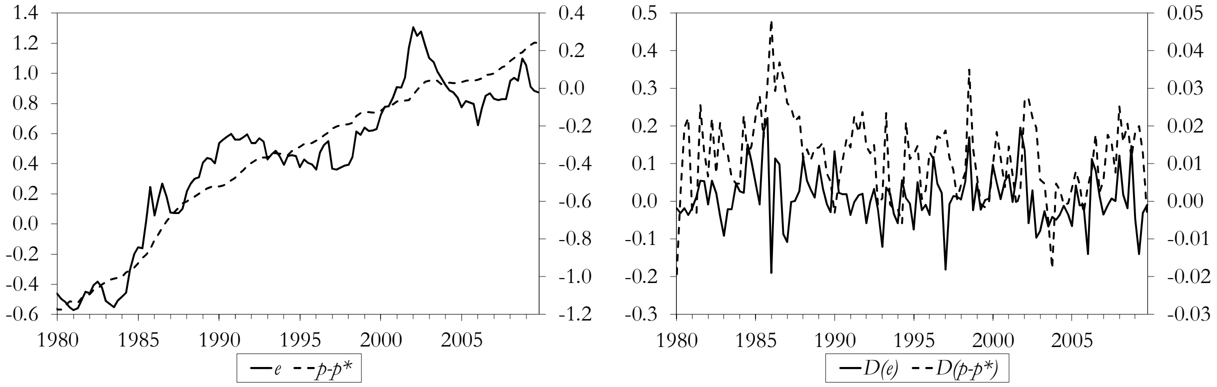
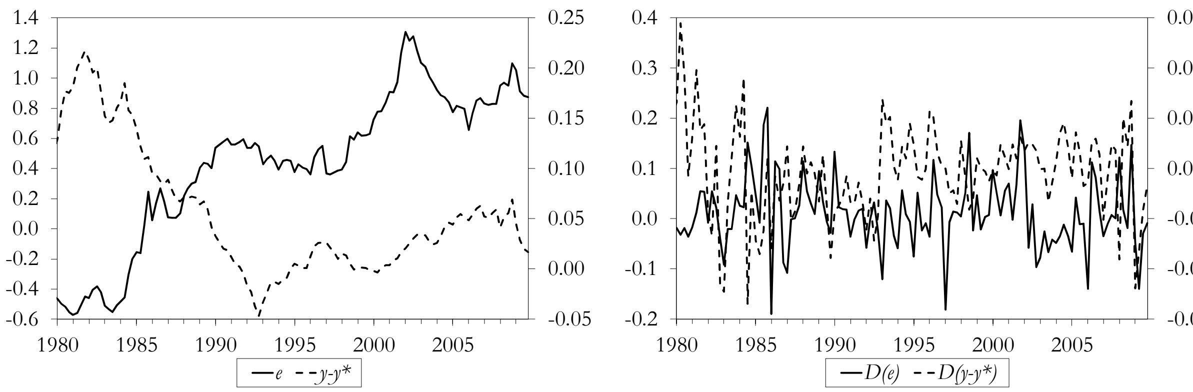
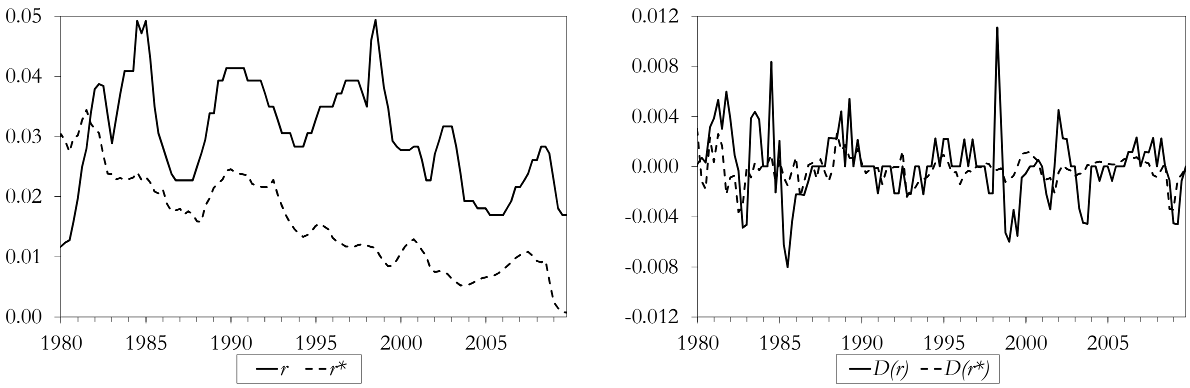


Figure 2.5 Exchange rate and ratio of domestic to foreign output



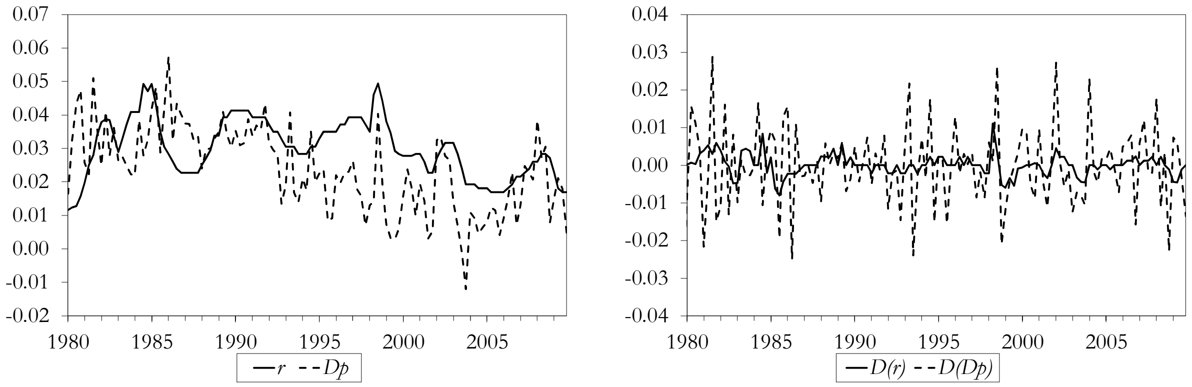
The UIP implies that the arbitrage process between domestic and foreign bonds will ensure that domestic and foreign interest rates will be in equilibrium in the long term. Figure 2.6 illustrates domestic and foreign short-term interest rates, first in levels and then in first differences. The short-term interest rates seem to have similar patterns over time, indicating that the UIP may hold for South Africa. The large gap between domestic and foreign rates is in line with expectations, since South Africa is a developing country and the higher interest rate rewards investors for the risk faced.

Figure 2.6 Domestic and foreign short-term interest rates



For the connection between the domestic interest rate and domestic inflation (LIR), the modified Fisher parity $(r-\beta_2\pi)$ is considered in addition to the usual Fisher parity $(r-\pi)$. Figure 2.7 shows this link, again in both levels and first differences. Interest rates (r) and inflation (π, denoted by Dp) seem to have the same long-term trends.

Figure 2.7 Short-term interest rates and inflation



For the money demand (MD) connection defined in Table 2.4, $m-\beta_3 y-\beta_4 r$, β_3 (the income elasticity) is expected to be positive and β_4 (the interest rate elasticity) is expected to be negative.

Figure 2.8 and Figure 2.9 confirm the anticipated relationships of money with output and interest rates respectively. The negative link between money and interest rates is only valid from late 1998 onwards.

Figure 2.8 Broad money (M3) and output

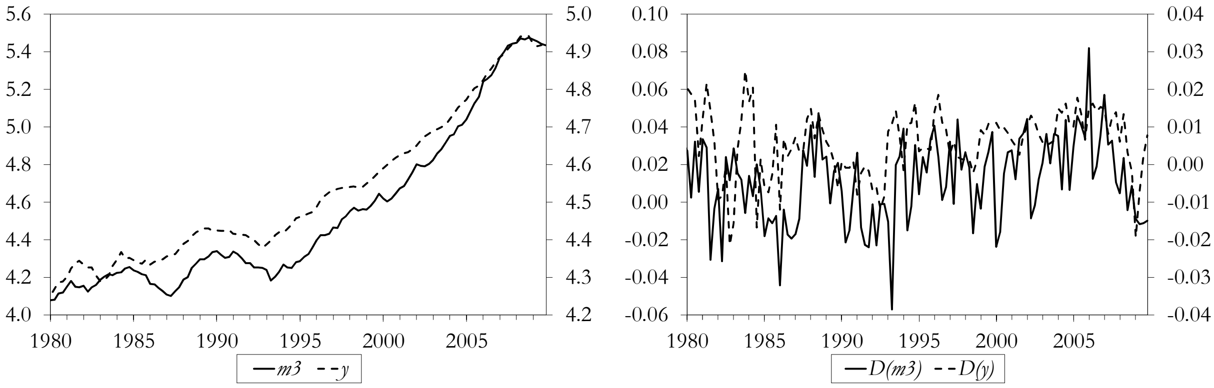
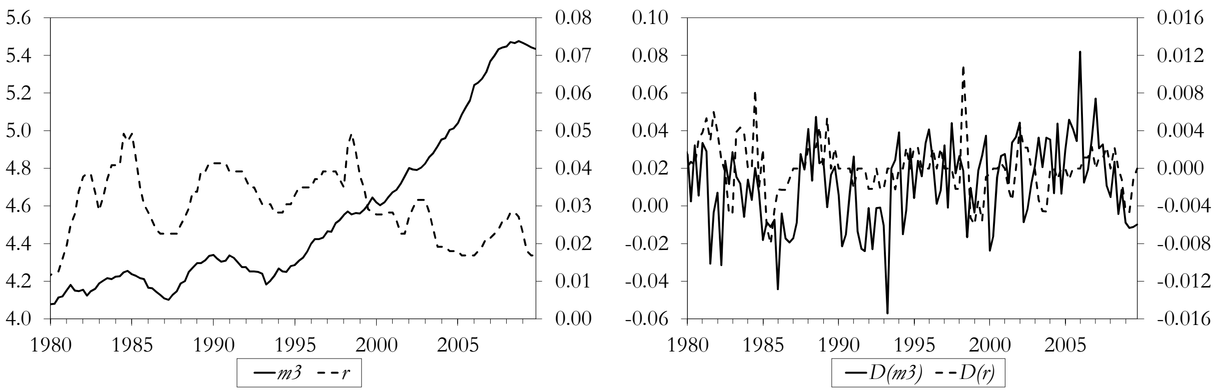
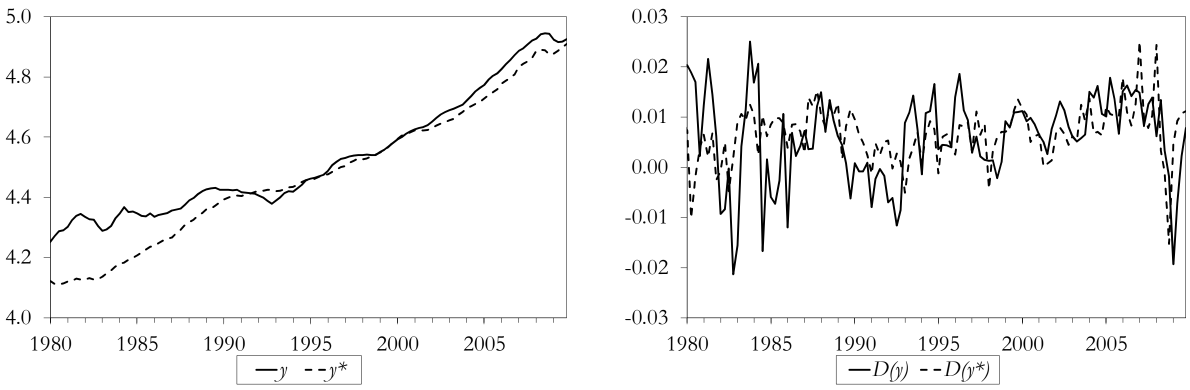


Figure 2.9 M3 and short-term interest rates



According to output convergence (GAP in Table 2.4), domestic and foreign output should converge in the long run. Figure 2.10, which includes the levels and first differences of domestic and foreign output, suggests that this relation may hold from 1994 onwards.

Figure 2.10 Domestic and foreign output



To determine whether the above long-run relations are valid, the ARDL cointegration approach (Pesaran & Shin, 1999; Pesaran *et al.*, 2001) is used. Table 2.5 summarises the formal test results.

Table 2.5 Long-term economic relationships: ARDL cointegration test results

	EC[a]	*t*-stat[b]	Critical value bounds[c]		*F*-stat[b]	Critical value bounds[c]		ARDL(*p*,*q*,*s*)[d]
PPP[A]	-0.16	-3.39*	-2.57	-3.21	3.91*	2.89[e]	3.86[e]	ARDL(4,0,1)
UIP	-0.12	-4.11*	-2.57	-2.91	8.01*	4.04	4.78	ARDL(2,0)
LIR	-0.10	-3.54*	-2.57	-2.91	5.42*	4.04	4.78	ARDL(2,0)
MD	-0.08	-2.94	-2.57	-3.21	3.81	3.17	4.14	ARDL(2,4,0)
GAP	-0.02	-1.19	-3.13	-3.40	2.24	5.59	6.26	ARDL(2,2)

[a] Error correction (EC) term.

[b] Significant *t*-stat or *F*-stat indicated by * (10% level of significance).

[c] Lower and upper 90% critical value bounds (Pesaran *et al.*, 2001).

[d] Lag lengths selected by the Akaike information criterion (AIC), with maximum four lags. The models include an intercept, except for PPP[A] that includes a dummy variable that equals one from 1992Q1 onwards (to represent the structural change in South Africa in the early 1990s) and GAP that includes an intercept and a trend. *p* is the lag order of the dependent variable, *q* is the lag order of the first independent variable and *s* is the lag order of the second independent variable.

[e] Lower and upper 90% critical value bounds from Microfit 5.0 (Pesaran & Pesaran, 2009a). These critical values are simulated stochastically to be valid in the presence of the dummy variable in PPP[A].

The PPP[A], UIP and LIR long-run relations are valid for South Africa over the sample period (1979Q2 to 2009Q4). The MD and GAP relations do not hold. Comparing South Africa's results to those from earlier VECX* studies (Table 2.4), the same long-run relations that hold for Indonesia are valid for South Africa.

To confirm the valid relations and to determine the causality of the relationships, the cointegrated VAR approach is also used. This suggests that the PPP^A, UIP and LIR long-run relationships are valid for South Africa. It further indicates that the direction of causality is in line with expectations, especially that domestic variables do not have an impact on foreign variables in the long term. It therefore verifies the assumption that the foreign variables are weakly exogenous.

The estimated long-term equations from the ARDL method for the valid relations are included as equations (2.3), (2.4) and (2.5); with the standard errors of the coefficients shown in brackets. The coefficient of π in the LIR relationship, equation (2.5), is statistically significant at a 10 per cent level, while all the other coefficients are statistically significant at one per cent or five per cent levels. In equation 2.3, the real effective exchange rate is ep, calculated from the nominal effective exchange rate and domestic prices ($ep = e - p$), while $d92$ is a dummy variable that is zero up to 1991Q4 and one from 1992Q1 onwards. The dummy variable is included to account for the structural change in South Africa in the early 1990s, following the release of Nelson Mandela and the lifting of economic sanctions in the period leading up to the institution of a democracy.

PPP^A: $ep_t = -0.754\, p_t^* - 1.779(y_t - y_t^*) - 0.349(d92_t) + \varepsilon_t^1$ (2.3)

(0.029) (0.840) (0.131)

UIP: $r_t = 0.018 + 0.649\, r_t^* + \varepsilon_t^2$ (2.4)

(0.004) (0.219)

LIR: $r_t = 0.021 + 0.392\,\pi_t + \varepsilon_t^3$ (2.5)

(0.005) (0.204)

In the UIP relationship, equation (2.4), the coefficient of r^* is not significantly different from one, but in the LIR relationship, equation (2.5), the coefficient of π is significantly different from one, suggesting that the modified Fisher parity may be more relevant. In the estimated PPP^A relationship, equation (2.3), the coefficient of p^* is significantly different from minus one. This suggests that although the ARDL and cointegrated VAR approaches indicate a significant long-run cointegrated relationship, that the augmented PPP relationship may not hold in its exact form. However, it should be taken into account that all these models are single-equation models. The VECX* will account for further interactions.

To summarise, the results from the data analysis indicate three potential long-term economic relations for the country. The next section shows that the VECX* cointegration test results do suggest three cointegrating relations.

2.6. VECX* MODEL RESULTS

The variables included in the VECX* model are based on the results of the preliminary data analysis. As indicated in Table 2.1, the domestic endogenous variables included in the VECX* model are real output (y), the quarterly inflation rate (π), the repo rate (r), the long-term interest rate (lr) and the real effective exchange rate (calculated as $ep = e - p$, from the nominal effective exchange rate and prices). The weakly exogenous variables are foreign real output (y^*), foreign prices (p^*), the foreign short-term interest rate (r^*) and the oil price (p^{oil}).

The VECX* model for South Africa was developed in Microfit 5.0 (Pesaran & Pesaran, 2009a; 2009b). The Akaike information criterion (AIC) indicates that the optimal model has two lags of the endogenous variables and one lag of the exogenous variables.

Table 2.6 contains the cointegration test results for the model with an unrestricted intercept, a restricted trend, a restricted dummy variable to account for shifts in long-run relations due to the structural change in South Africa in the early 1990s ($d92$), and an unrestricted differenced dummy variable to allow for shifts in short-run dynamics due to the structural change ($D(d92)$). A deterministic trend is included since most of the variables are trended; however, the trend is restricted to lie within the cointegrating space to avoid the possibility of quadratic trends in the solution of the model in levels. The marginal models for the weakly exogenous foreign variables each include one lag for the differenced endogenous variables, one lag for the differenced exogenous variables and an intercept. In Table 2.6, the maximum eigenvalue statistic suggests a rank of three at a 10 per cent level of significance, while the trace statistic indicates a rank of three at a five per cent level of significance. Thus, there are three cointegrating relationships in the model, which are in line with the three significant long-run economic relations identified in Section 2.5.

Table 2.6 Cointegration test results

		Maximum Eigenvalue		
Null	Alternative	**Statistic**	95% critical value	90% critical value
r = 0	r = 1	**65.76**	52.34	49.18
r ≤ 1	r = 2	**58.49**	45.42	41.89
r ≤ 2	**r = 3**	**36.83**	37.79	34.81
r ≤ 3	r = 4	**19.45**	30.05	27.44
r ≤ 4	r = 5	**17.39**	21.78	19.06
		Trace		
Null	Alternative	**Statistic**	95% critical value	90% critical value
r = 0	r ≥ 1	**197.92**	135.94	130.02
r ≤ 1	r ≥ 2	**132.16**	100.48	95.03
r ≤ 2	**r ≥ 3**	**73.67**	68.97	64.71
r ≤ 3	r ≥ 4	**36.84**	43.34	40.08
r ≤ 4	r = 5	**17.39**	21.78	19.06

The critical values are simulated using 3000 replications. The critical values for two exogenous variables are considered, since there are two cointegrating relationships between the four exogenous variables.

These relations are the augmented purchasing power parity (PPP^A), the uncovered interest parity (UIP) and the modified Fisher parity (LIR). The restrictions of these relations are imposed on the VECX* to identify the model. The first cointegrating vector relates to PPP^A, which can be written as $ep + p^* - \beta_1\left(y - y^*\right)$. The coefficients of ep and p^* are restricted to one (1), while the coefficients of the following variables are restricted to zero: π, r, lr, r^*, p^{oil}, $trend$ and $d92$. In the second cointegrating vector, relating to UIP or $r - r^*$, the restrictions are: coefficient of one (1) for r, coefficient of negative one (-1) for r^* and coefficients of zero for the other variables (y, π, lr, ep, y^*, p^*, p^{oil}, $trend$ and $d92$). The third cointegrating vector, relating to LIR or $r - \beta_2\pi$, makes the following restrictions: coefficient of negative one (-1) for r and coefficients of zero for y, lr, ep, y^*, p^*, r^*, p^{oil}, $trend$ and $d92$.

The estimates of the overidentified cointegrating vectors are shown in equations (2.6), (2.7) and 2.8); with the standard errors of the estimated coefficients shown in brackets. Both estimated coefficients (β_1 and β_2) are statistically significant at a one per cent level. The intercepts of the three equations are b_{10}, b_{20} and b_{30} respectively, while the error correction terms are ξ_{1t}, ξ_{2t} and ξ_{3t}.

PPP^A: $ep_t = - p_t^* - 2.534(y_t - y_t^*) + b_{10} + \xi_{1t}$ (2.6)

(0.827)

UIP: $r_t = r_t^* + b_{20} + \xi_{2t}$ (2.7)

LIR: $r_t = 0.781\,\pi_t + b_{30} + \xi_{3t}$ (2.8)

(0.204)

The estimates from equation (2.6) and equation (2.8) are in line with those of the Indonesian model (Affandi, 2007), where the same restrictions were imposed.

The log-likelihood ratio (LR) test, which has a $\chi^2(22)$ distribution, marginally rejects the 22 overidentifying restrictions. The LR test statistic of 85.53 is above the 99 per cent bootstrapped critical value of 80.83 (based on 3000 simulations). Since the LR test often over-rejects the null hypothesis that the restrictions are valid (Pesaran & Pesaran, 2009b), I decide to use the model with the overidentifying restrictions given the strong theoretical foundations of the three long-run relations. This decision is in line with that of Assenmacher-Wesche and Pesaran (2009), who proceeds with the overidentifying restrictons for their VECX* model for Switzerland despite the rejection of overidentifying restrictions based on the LR test statistic. Overall, the VECX* performs fairly well according to the reduced-form error correction equations and the diagnostic statistics. The persistence profiles converge to zero and the generalised impulse response functions stabilise quickly, which would not have been the case if the long-run cointegrating restrictions were invalid.

Table 2.7 shows the reduced-form error correction equations and the diagnostic statistics of the VECX*. The lagged error correction terms from the long-run relations, also known as deviations, are significant in several equations. Deviations from the PPP^A explain inflation and real effective exchange rates. The deviation of the domestic repo rate from the foreign short-run interest rate is significant in the output, inflation, repo rate and long-run interest rate differential equations. A deviation from LIR explains changes in inflation.

The diagnostic test results indicate that the residuals do not have normal distributions in most of the equations. At a 10 per cent level of significance, there is also some serial correlation in the equations for inflation and the real effective exchange rate, while there is misspecification in the interest rate equation. However, the equations pass most of the diagnostic tests. It can be noted that the diagnostic test results are superior to that of the Swiss VECX* model (Assenmacher-Wesche & Pesaran, 2009), where more of the null hypothesis for normally distributed residuals, no serial correlation, homoscedasticity and correct functional form are rejected.

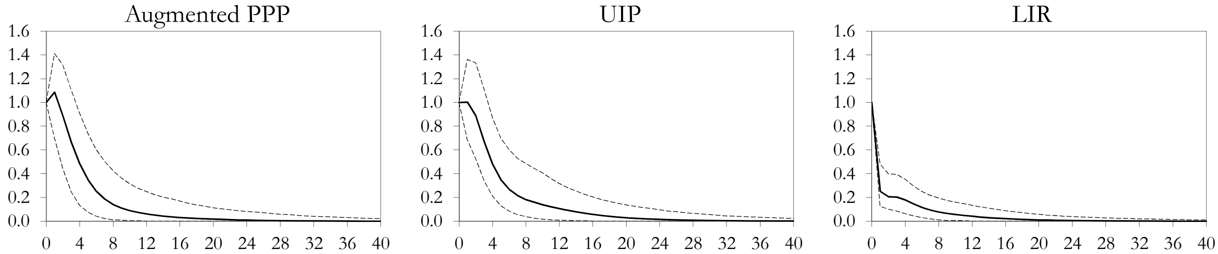
Table 2.7 Reduced-form error correction equations

Equation	Δy_t	$\Delta \pi_t$	Δr_t	Δep_t	Δlr_t
$\xi_{1,t-1}$	-0.011	0.016*	-0.002	-0.077*	-0.001
$\xi_{2,t-1}$	-0.274*	-1.060*	-0.124*	0.360	-0.073*
$\xi_{3,t-1}$	0.002	0.959*	-0.035	-0.205	-0.028
Δy_{t-1}	0.468*	0.063	0.066*	0.141	-0.009
$\Delta \pi_{t-1}$	0.019	0.031	0.044*	0.128	0.037*
Δr_{t-1}	0.102	0.402	0.036*	2.217	0.092
Δep_{t-1}	-0.010	0.016	0.000	0.124	0.002
Δlr_{t-1}	0.441	0.645	0.001	-4.594	0.095
Δy^*_t	0.180	0.112	-0.013	1.445	0.034
Δp^*_t	-0.209	-0.575*	-0.031	0.559	-0.009
Δr^*_t	-0.004	0.624*	0.148	-0.825	-0.102
Δp^{oil}_t	0.010*	0.011*	0.001	-0.059	0.002*
Intercept	0.018*	-0.008	0.002	0.038	0.002
$\Delta d92$	-0.008	-0.004	-0.002	-0.077	-0.001
Adjusted R^2	0.420	0.404	0.300	0.096	0.118
Serial correlation: $\chi^2(4)$	4.696	8.761*	1.361	8.523*	3.053
Functional form: $\chi^2(1)$	0.357	0.296	3.287*	0.220	0.959
Normality: $\chi^2(2)$	62.699*	1.137	237.57*	18.771*	35.252*
Heteroscedasticity: $\chi^2(1)$	0.006	0.010	0.006	0.300	0.034

An asterisk denotes significance at the 10% level.

A persistence profile (PP) traces the impact of a shock to the system on a cointegrating vector. The PPs of the three cointegrating vectors (Figure 2.11) of this VECX* converge to zero, indicating that the model will return to its long-run equilibrium following a shock to the system.

Figure 2.11 Persistence profiles of the effect of a system-wide shock to the cointegrating vectors with 95% bootstrapped confidence intervals

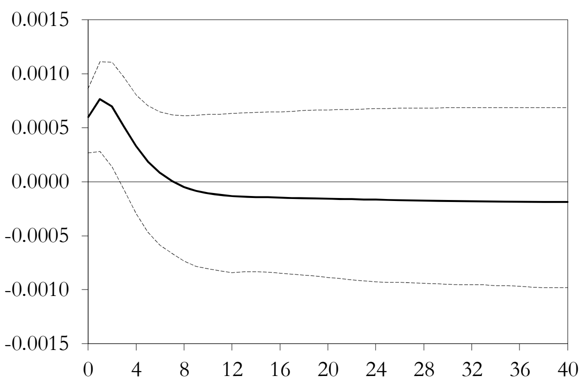


The PPs of this model were compared with those of the Indonesian model (Affandi, 2007). The PP of the augmented PPP for South Africa is more stable with smaller confidence intervals than the one for Indonesia. The PPs of the UIP and LIR relations for Indonesia return to their long-run equilibrium at a faster pace than the PPs for South Africa, but the PP of UIP for Indonesia shows an impact on the cointegrating vector after a system-wide shock that is twice the size of that for the PP of UIP for South Africa.

A generalised impulse response function (GIRF) shows the impact of a one standard error shock to a specific variable on that variable and other variables in the system. The GIRFs of this model are generally in line with expectations. Section A.3 in Appendix A contains all the GIRFs for the VECX* model.

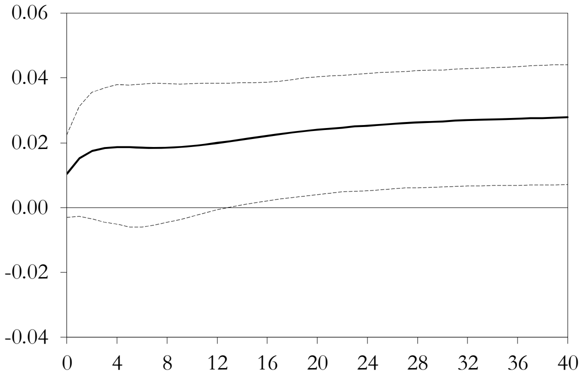
According to the traditional interest rate channel of the monetary transmission mechanism, expectations are that other interest rates will increase following an increase in the repo rate. Other short-term interest rates are not included in the model, but looking at Figure 2.12, long-term interest rates do increase in the short run before falling again. The impact becomes insignificant after three quarters.

Figure 2.12 Generalised impulse response for the long-run interest rate to a one standard error shock to the repo rate with 95% bootstrapped confidence intervals



From the exchange rate channel, the expectation is that higher short-term interest rates will result in an appreciation of the exchange rate. The appreciation of the real effective exchange rate following an increase in the repo rate is evident in Figure 2.13, but the impact is only statistically significant after three years.

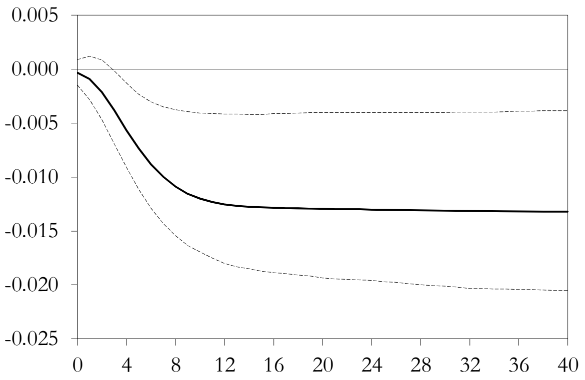
Figure 2.13 Generalised impulse response for the real effective exchange rate to a one standard error shock to the repo rate with 95% bootstrapped confidence intervals



The transmission mechanism of monetary policy suggests that an increase in the official short-term interest rate (repo rate for South Africa) will affect output and inflation negatively. The time lags, between an increase in the repo rate and the full negative impacts on respectively output and inflation, are around 12 and 24 months.

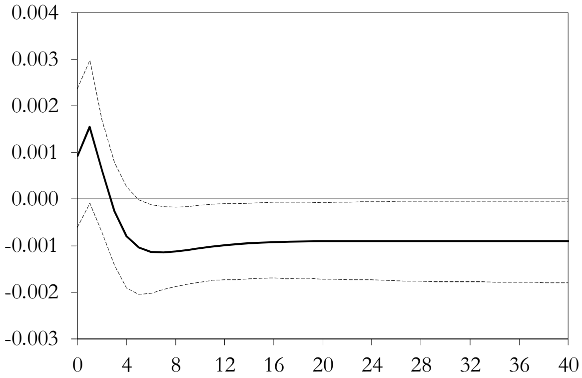
Figure 2.14 indicates that a positive shock to the official interest rate results in a decline in real output. Output is one of the intermediate targets of monetary policy. The movement is in line with *a priori* expectations, except that output does not start to recover after 12 months.

Figure 2.14 Generalised impulse response for output to a one standard error shock to the repo rate with 95% bootstrapped confidence intervals



The effect of a monetary policy shock on inflation (the ultimate target of monetary policy) is in line with *a priori* expectations. The effect of a shock to the monetary policy interest rate (repo rate) on the inflation rate, as illustrated in Figure 2.15, suggests a monetary policy lag of around 24 months (8 quarters).

Figure 2.15 Generalised impulse response for inflation to a one standard error shock to the repo rate with 95% bootstrapped confidence intervals



A statistically insignificant 'price puzzle' is only observed in the first quarter following the monetary policy shock. Thereafter, the inflation rate declines as anticipated in response to the interest rate increase. The same movements with monetary policy lags of about eight quarters are evident in the relevant impulse response functions of the models for Switzerland (Assenmacher-Wesche & Pesaran, 2009), Thailand (Akusuwan, 2005) and Indonesia (Affandi, 2007). Alternative specifications of the model for South Africa, for example with the addition of the gold price as one of the weakly exogenous foreign variables, do not solve the one-quarter 'price puzzle'. The models of Assenmacher-Wesche and Pesaran (2009), Akusuwan (2005), and Affandi (2007) also exhibit 'price puzzles', which generally lasted longer.

The model in this study utilised foreign variables created using three-year moving average trade weights. When the same model is estimated with foreign variables calculated with fixed trade weights (average trade weights between 2007 and 2009), specification problems emerge. This is not surprising, given the dissimilarities of the foreign variables calculated using the two contrasting methods. Figure 2.1 in Section 2.1 illustrates that the foreign variables based on fixed trade weights show larger variation than the foreign variables based on time-varying trade weights. By not taking into account the large movements in trade weights, thus by using the fixed-weighted foreign variables with more variation, the PPs of the model take much longer to converge and the GIRFs do not stabilise. Therefore, the results of the model that includes fixed trade-weighted foreign variables cannot be interpreted with confidence.

The VECX* model that includes time-varying trade-weighted foreign variables shows the expected transmission of monetary policy in South Africa between 1979 and 2009, with results in line with those of VECX* models for other countries.

2.7. CONCLUSION

In this chapter, a new type of model for South Africa is developed to investigate the 'timing and effect' (Mishkin, 1995) of a monetary policy change on inflation. The model includes foreign variables calculated from time-varying trade-weighted data for 32 countries, due to substantial changes in South Africa's main trading partners. This is also a first for South Africa, since previous models either use the US as a proxy for the rest of the world, or they use trade-weighted data for a fixed period to calculate foreign variables. Three statistically significant long-run economic relations identify the model. These are the purchasing power parity (PPP), the uncovered interest parity (UIP) and the Fisher parity (LIR). The lag between a change in the repo rate and the full impact on inflation is around 24 months. The VECX* model thus shows the effective transmission of monetary policy in South Africa between 1979 and 2009.

In the next chapter, a GVAR model, that contains individual VECX* models for South Africa and 32 other countries, is used to explore the changing effect of GDP shocks in the US and China respectively on South Africa. This is of interest given the large change in trade of South Africa with China and the US as is evident from Figure 1.1 in Section 1.1.

CHAPTER 3

THE IMPACT OF ECONOMIC SHOCKS IN THE REST OF THE WORLD ON SOUTH AFRICA: EVIDENCE FROM A GLOBAL VAR MODEL

3.1. INTRODUCTION

South Africa is a small open economy. One therefore expects that the major movements observed in the trade shares of the country's trading partners, mainly since the mid-1990s, together with changes in global trade linkages, would affect the interactions of the South African economy with the economies of its trading partners. This chapter confirms this expectation, since it shows that the impact of economic shocks in the rest of the world on South Africa has changed considerably with the change in trade patterns. The increased trade with China makes South Africa much more vulnerable to GDP shocks to the Chinese economy and less vulnerable to GDP shocks to the US economy. It is important for policy makers to consider this during scenario analysis and forecasting.

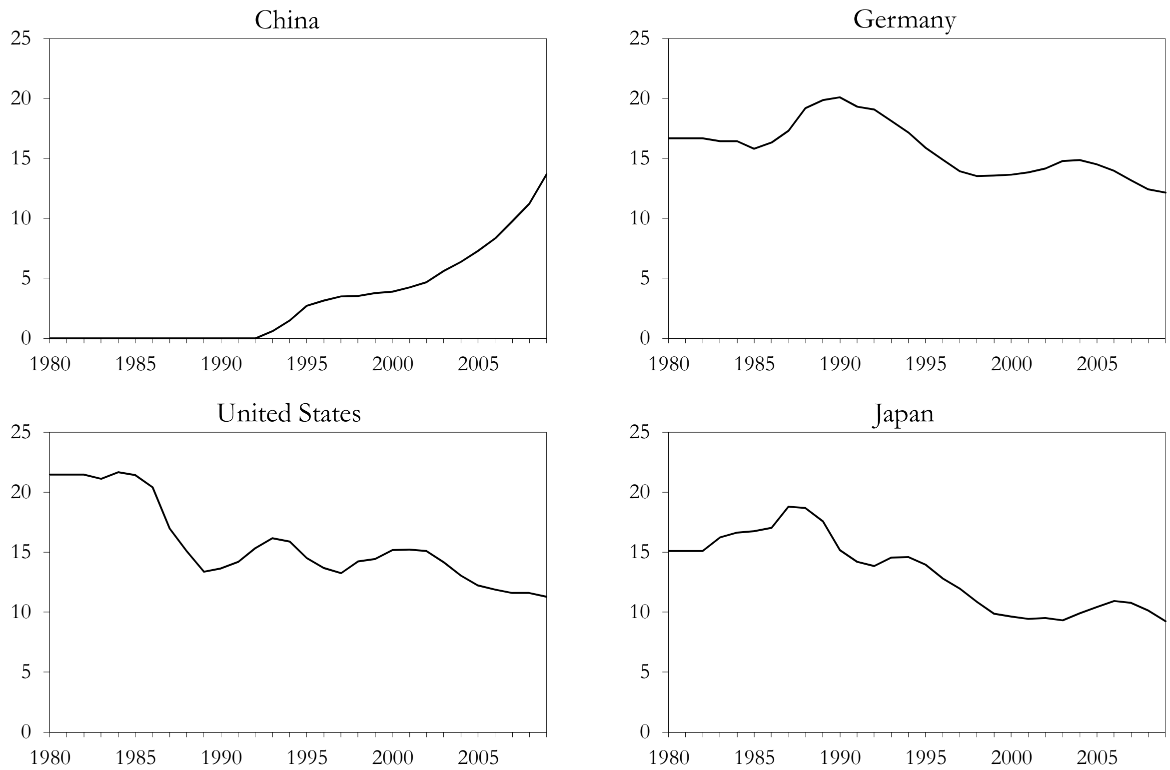
In this chapter, I use the GVAR methodology as introduced, explained and expanded by Pesaran *et al.* (2004), Garratt *et al.* (2006) and Dées *et al.* (2007a). The GVAR approach incorporates global trade linkages, which enables analysis of the interactions between economies and the transmission of shocks to individual countries and/or specific regions (Di Mauro & Pesaran, 2013). This type of analysis is not possible using a factor-augmented vector autoregression (FAVAR) or a standalone DSGE model. A GVAR with data for 33 countries from 1979Q2 to 2009Q4 is modelled. Due to the significant change in global trade linkages, the country-specific foreign variables in the GVAR are created with three-year moving average trade weights. The study follows the model specification of Cesa-Bianchi *et al.* (2012), who investigate the impact of China's growth on business cycles in Latin America.

Along the lines of Cesa-Bianchi *et al.* (2012), the GVAR is solved a number of times – each time with a different configuration of cross-country interdependencies. It is then possible to determine the change over time in the effect of GDP shocks in China and the US on South Africa. All the country-specific model estimations utilise time-varying foreign variables, while the GVAR is solved four times – each time using the fixed trade weights for a different year (1995, 2000, 2005 and 2009) – to compare the effects of the changing trade weights.

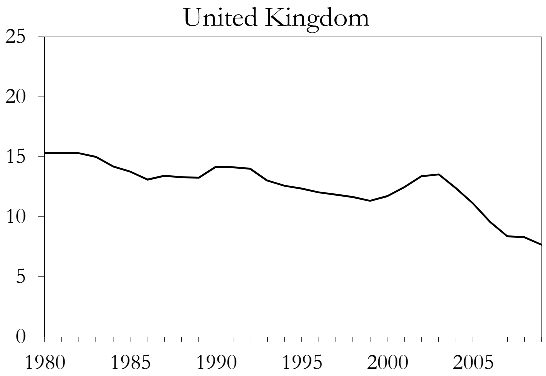
To my knowledge, this is the first study for South Africa that investigates the impact of changes in international trade linkages on the transmission of international shocks to the South African economy, with the use of time-varying trade-weighted foreign data. The one South African application of the GVAR (Çakır & Kabundi, 2013) focuses on the transfer of trade shocks between the BRIC (Brazil, Russia, India and China) countries and South Africa. The foreign variables for the individual country models are constructed with fixed trade weights, which do not take into account the substantial change in South Africa's trade linkages.

The movements in the trade shares from 1980 to 2009 of the five main trading partners of South Africa are illustrated in Figure 3.1[5].

Figure 3.1 Three-year moving average trade weights (%) of the five main trading partners



[5] The trade weights are from the '2009 Vintage' GVAR dataset of the GVAR Toolbox 1.1 (Smith & Galesi, 2011).



The five largest trading partners of South Africa currently are (in order of importance) China, Germany, the US, Japan and the UK. South Africa did not trade with China before 1993, but due to significant growth in trade, China overtook Germany in 2009 as the main trading partner of South Africa. Trade with the other main trading partners declined noticeably over the same period.

Di Mauro and Pesaran (2013) highlight several additional advantages of the GVAR, which further motivates the use of the GVAR framework for this study. It is a compact model that provides a solution to the 'curse of dimensionality', which is typically associated with high-dimensional models, through the estimation of VECMs, conditional on weakly exogenous foreign variables, for each country in the model. The GVAR allows for both long-run and short-run economic relations. It further accounts for various international transmission channels: common observed global factors (e.g. an oil price shock), unobserved global factors (e.g. pervasive technological progress), specific national factors, and residual interdependencies resulting from policy or trade spillovers. The framework is very suitable for macroeconomic policy analysis as it accounts for global interdependencies.

In the next section, the relevant literature is reviewed. Section 3.3 explains the GVAR methodology, while Section 3.4 shows the specification and estimation of the GVAR. Section 3.5 contains the results of shocks to the GVAR, which illustrates the change in the effect of economic shocks on South Africa over time, and Section 3.6 concludes.

3.2. LITERATURE REVIEW

Pesaran *et al.* (2004) introduced the GVAR framework to model regional interdependencies. Dées *et al.* (2007a) and Dées, Holly, Pesaran and Smith (2007b) respectively extended the GVAR framework to investigate global linkages of the Euro area and to test long-run macroeconomic relationships.

The GVAR literature has grown rapidly over the last few years. Early applications of the GVAR approach include modelling credit risk in a globalised economy (Pesaran, Schuermann & Treutler, 2007a), determining the impact if the UK and Sweden had entered the Euro in 1999 (Pesaran, Smith & Smith, 2007b) and forecasting with a GVAR (Pesaran, Schuermann & Smith, 2009a; 2009b).

Di Mauro and Pesaran (2013) divide recent applications of the GVAR into three categories. These categories are international transmission and forecasting (Eickmeier & Ng, 2013; Galesi & Lombardi, 2013; Garratt, Lee & Shields, 2013; Greenwood-Nimmo, Nguyen & Shin, 2013; Lui & Mitchell, 2013; Smith, 2013a; Smith, 2013b), finance applications (Al-Haschimi & Dées, 2013; Favero, 2013; Nickel & Vansteenkiste, 2013) and regional applications (Assenmacher, 2013; Cesa-Bianchi *et al.*, 2013; Dées, 2013; Fielding, Lee & Shields, 2013; Galesi & Sgherri, 2013).

Dées, Pesaran, Smith and Smith (2010) extend the GVAR into a Multi-Country New Keynesian (MCNK) model, by basing it on a three-equation structural DSGE model, due to the difficulty to use 'reduced-form multi-country VARs to examine the effects of structural shocks with clear economic interpretation'. Smith (2013b) discusses the theoretical framework of the MCNK model. The individual country models in the MCNK model determine inflation (with a Phillips curve), output (with an IS curve), interest rates (with a Taylor rule) and real exchange rates. The data are the deviations of variables from their steady state values. While shocks applied to the usual unrestricted GVAR are correlated within and across countries, shocks applied to the MCNK model are uncorrelated within countries due to the structural identification of the shocks. Due to the underlying structural theory, the nature and source of shocks can be determined. This enables Dées *et al.* (2010) to use the MCNK model to determine the clear effects of the following country-specific or global identified shocks: supply, demand and monetary policy shocks. The study highlights the importance of the incorporation of global interdependencies in economic modelling.

The study of Cesa-Bianchi *et al.* (2012), with the condensed version in Cesa-Bianchi *et al.* (2013), has a similar purpose to this research, but it focuses on Latin America. Their GVAR includes data from 1979Q2 to 2009Q4, with the foreign variables composed using time-varying trade weights. The GVAR is solved four times, each time with the fixed trade weights of a different year. The solution dates (1985, 1995, 2005 and 2009) differ from the solution dates of this study. Different years (1995, 2000, 2005 and 2009) are used, since trade sanctions against South Africa limited trade in the 1980s and South Africa did not trade with China before 1993. The authors of the Latin America study use their GVAR model to show how the impressive growth in China's economy, especially in its exports, and the resulting increase in trade with Latin America have affected business cycles in five Latin American countries (Argentina, Brazil, Chile, Mexico and Peru). The long-run effect of a GDP shock to the US on the five Latin American countries has halved since 1995, while the long-run effect of a GDP shock to China on Latin America has tripled over this period. Cesa-Bianchi *et al.* (2012) find that these results, especially the lower dependence of the Lation American region on the US, partly explain why the impact of the recent global crisis on the five Latin American countries was smaller and lasted shorter than initially expected.

As mentioned in Section 3.1, Çakır and Kabundi (2013) use a GVAR model to analyse the trade linkages between South Africa and the BRIC countries between 1995Q1 and 2009Q4. Fixed trade weights are used to calculate the foreign variables of each of the countries in the GVAR. The domestic variables in the model include real GDP, inflation, exchange rates, real exports and real imports, while the foreign variables are real GDP and inflation. The oil price is a global variable that is included as domestic in the model of the dominant country (the US) and as foreign in the models of the other countries. Their main finding is that export shocks to each of the BRIC countries affect South African imports and GDP significantly.

This is the first GVAR study that shows how the emergence of China in the global economy affects South Africa and its main trading partners in the context of using time-varying trade-weighted foreign data rather than fixed trade-weighted foreign data.

Critique against the GVAR include that the shocks cannot be interpreted as demand, supply or monetary policy shocks, due to the lack of economic structure (Smith, 2013b). Dées *et al.* (2010) therefore combine the GVAR with a structural DSGE model, to enable the economic interpretation of structural shocks. The maintenance of a GVAR model is cumbersome, since a data update includes sourcing data for all the variables for all the countries included in the GVAR and sourcing updated weighs (mostly trade weights). The forecasting ability of the GVAR over simpler models is also limited (see Chapter 4). However, the virtues of GVAR modelling far outweigh the shortcomings.

3.3. GVAR METHODOLOGY

This section describes the theoretical GVAR model introduced, explained and expanded by Pesaran *et al.* (2004), Pesaran and Smith (2006), Garratt *et al.* (2006), Dées *et al.* (2007a), Dées *et al.* (2007b), Smith (2011), and Di Mauro and Pesaran (2013). The notation is from Di Mauro and Smith (2013), who replicate the study of Dées *et al.* (2007a) using an updated data set.

The GVAR is a global model that combines many individual country models. It includes distinct VECMs with weakly exogenous foreign variables, denoted by VECX*, for every country in the GVAR. The VECX* models include domestic variables and weakly exogenous (X) country-specific foreign (*) variables. The GVAR uses a weight matrix, in this case a trade matrix, to link the countries through weighted country-specific foreign variables. The GVAR could also include global variables (e.g. the oil price), which may enter the dominant country as endogenous and all the other countries as weakly exogenous.

3.3.1 Country-specific VECX* models

The assumption of weak exogeneity of the country-specific foreign variables, in the VECX* country models, implies that the foreign variables are long-run forcing for the domestic variables. Therefore, foreign variables affect domestic variables in the long term, but domestic variables do not affect foreign variables in the long term. Contemporaneous correlations between domestic and foreign variables are allowed. Weak exogeneity tests (see Section 3.4 for more information) usually show that the assumption is correct, as expected, since most countries have small or relatively small open economies. The US economy is the exception, being the dominant economy in the GVAR due to its dominance in global equity and bond markets. China's share in the global economy is increasing, but the US still has the largest share. Chudik and Smith (2013) motivate the use of the US as the dominant country by showing that it continues to be the major source of global economic interdependence.

The weak exogeneity assumption is key to the GVAR framework, since it enables the individual estimation of country-specific VECX* models before solving these models for the endogenous variables in the system, thereby avoiding the 'curse of dimensionality'. To satisfy the assumption of weak exogeneity, small countries (such as South Africa) generally require a large number of countries in the system, while large countries or regions (such as the US) require a small number of countries (Smith, 2011).

Before selecting the number of cointegrating relations for each country, individual VARX* models are estimated. VARX*(p_i, q_i) models are vector autoregressive (VAR) models with weakly exogenous (X) foreign (*) variables. The lag orders of the domestic and foreign variables, respectively p_i and q_i, are determined using the Akaike information criterion (AIC) or the Schwarz Bayesian criterion (SBC). Suppose a VARX*(2,2) structure for country i:

$$\mathbf{x}_{it} = \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \mathbf{\Phi}_{i1}\mathbf{x}_{i,t-1} + \mathbf{\Phi}_{i2}\mathbf{x}_{i,t-2} + \mathbf{\Lambda}_{i0}\mathbf{x}^*_{it} + \mathbf{\Lambda}_{i1}\mathbf{x}^*_{i,t-1} + \mathbf{\Lambda}_{i2}\mathbf{x}^*_{i,t-2} + \mathbf{u}_{it}\,, \tag{3.1}$$

where $i = 0, 1, 2, \ldots, N$ and $t = 1, 2, \ldots, T$. The global model contains data for $N + 1$ countries, with country 0 the reference country, over T time periods. $\mathbf{x}_{it}$ is a $k_i \times 1$ vector of domestic $I(1)$ variables, $\mathbf{x}^*_{it}$ is a $k^*_i \times 1$ vector of country-specific foreign $I(1)$ variables, and $\mathbf{u}_{it}$ is a process with no serial correlation, but with weak dependency over cross sections.

The domestic variables are endogenous to the system, while the foreign variables are weakly exogenous. Any global variables are endogenous in the model of the dominant country, but weakly exogenous in all the other country models. k_i and k^*_i can differ for each country. Either fixed trade weights or time-varying trade weights are used to construct the foreign variables for each country from the matching domestic variables of the other countries. Thus, $\mathbf{x}^*_{it} = \sum_{j=0}^{N} w_{ij}\mathbf{x}_{jt}$, where w_{ij} are trade weights that reflect the trade share of country j (with j = 0, 1, 2, … , N) in the trade (average of exports and imports) of country i. The weights are predetermined and satisfy the conditions $w_{ii} = 0$ and $\sum_{j=0}^{N} w_{ij} = 1$.

During the estimation process, the number of cointegrating relations (interpreted as the long-run relations) is determined. A possible VECX* representation, which includes the short-run and long-run relations, of equation (3.1) is

$$\Delta\mathbf{x}_{it} = \mathbf{c}_{i0} - \boldsymbol{\alpha}_i\boldsymbol{\beta}'_i\left[\mathbf{z}_{i,t-1} - \boldsymbol{\gamma}_i(t-1)\right] + \mathbf{\Lambda}_{i0}\Delta\mathbf{x}^*_{it} + \Gamma_i\Delta\mathbf{z}_{i,t-1} + \mathbf{u}_{it}\,, \tag{3.2}$$

where $\mathbf{z}_{it} = \left(\mathbf{x}'_{it}, \mathbf{x}'^*_{it}\right)'$. $\boldsymbol{\alpha}_i$ is a $k_i \times r_i$ matrix with the speed of adjustment coefficients and $\boldsymbol{\beta}_i$ is a $\left(k_i + k^*_i\right) \times r_i$ matrix with the cointegrating vectors. The rank of both $\boldsymbol{\alpha}_i$ and $\boldsymbol{\beta}_i$ is r_i. The r_i error-correction terms of equation (3.2) can be rewritten as

$$\beta_i'(\mathbf{z}_{it} - \gamma_i t) = \beta_{ix}'\mathbf{x}_{it} + \beta_{ix^*}'\mathbf{x}_{it}^* - (\beta_i'\gamma_i)t, \tag{3.3}$$

if β_i is partitioned as $\beta_i = (\beta_{ix}', \beta_{ix^*}')'$. Thus, cointegration is possible in $\mathbf{x}_{it}$, between $\mathbf{x}_{it}$ and $\mathbf{x}_{it}^*$, and between $\mathbf{x}_{it}$ and $\mathbf{x}_{jt}$ when $i \neq j$.

When estimating the VECX* models for each country, $\mathbf{x}_{it}^*$ is seen as long-run forcing or weakly exogenous to the coefficients of equation (3.2). For the model of each country, r_i (the rank), α_i (the speed of adjustment coefficients) and β_i (the cointegrating vectors) are determined.

3.3.2 GVAR model solution

After the estimation of the VECX* models for each country, the GVAR model is solved for all the countries for all the endogenous variables ($k = \sum_{i=0}^{N} k_i$) in the global system.

Use $\mathbf{z}_{it} = (\mathbf{x}_{it}', \mathbf{x}_{it}'^*)'$ to rewrite the VARX*(2,2) models from equation (3.1) as

$$\mathbf{A}_{i0}\mathbf{z}_{it} = \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \mathbf{A}_{i1}\mathbf{z}_{i,t-1} + \mathbf{A}_{i2}\mathbf{z}_{i,t-2} + \mathbf{u}_{it}, \tag{3.4}$$

with $\mathbf{A}_{i0} = (\mathbf{I}_{ki}, -\mathbf{\Lambda}_{i0})$, $\mathbf{A}_{i1} = (\mathbf{\Phi}_{i1}, \mathbf{\Lambda}_{i1})$ and $\mathbf{A}_{i2} = (\mathbf{\Phi}_{i2}, \mathbf{\Lambda}_{i2})$.

Then derive the identity $\mathbf{z}_{it} = \mathbf{W}_i\mathbf{x}_t$ where $\mathbf{x}_t = (\mathbf{x}_{0t}', \mathbf{x}_{1t}', \ldots, \mathbf{x}_{Nt}')$ is a $k \times 1$ vector of endogenous variables and $\mathbf{W}_i$ is a $(k_i + k_i^*) \times k$ link matrix. $\mathbf{W}_i$ is constructed from the country-specific trade weights w_{ij}. Use the identity to write equation (3.4) as

$$\mathbf{A}_{i0}\mathbf{W}_i\mathbf{x}_t = \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \mathbf{A}_{i1}\mathbf{W}_i\mathbf{x}_{t-1} + \mathbf{A}_{i2}\mathbf{W}_i\mathbf{x}_{t-2} + \mathbf{u}_{it}. \tag{3.5}$$

For a model of the endogenous variables $\mathbf{x}_t$, the individual country models are stacked to obtain

$$\mathbf{G}_0\mathbf{x}_t = \mathbf{a}_0 + \mathbf{a}_1 t + \mathbf{G}_1\mathbf{x}_{t-1} + \mathbf{G}_2\mathbf{x}_{t-2} + \mathbf{u}_t, \tag{3.6}$$

where $\mathbf{G}_0 = \begin{pmatrix} \mathbf{A}_{00}\mathbf{W}_0 \\ \mathbf{A}_{10}\mathbf{W}_1 \\ \vdots \\ \mathbf{A}_{N0}\mathbf{W}_N \end{pmatrix}$, $\mathbf{a}_0 = \begin{pmatrix} \mathbf{a}_{00} \\ \mathbf{a}_{10} \\ \vdots \\ \mathbf{a}_{N0} \end{pmatrix}$, $\mathbf{a}_1 = \begin{pmatrix} \mathbf{a}_{01} \\ \mathbf{a}_{11} \\ \vdots \\ \mathbf{a}_{N1} \end{pmatrix}$, $\mathbf{G}_1 = \begin{pmatrix} \mathbf{A}_{01}\mathbf{W}_0 \\ \mathbf{A}_{11}\mathbf{W}_1 \\ \vdots \\ \mathbf{A}_{N1}\mathbf{W}_N \end{pmatrix}$, $\mathbf{G}_2 = \begin{pmatrix} \mathbf{A}_{02}\mathbf{W}_0 \\ \mathbf{A}_{12}\mathbf{W}_1 \\ \vdots \\ \mathbf{A}_{N2}\mathbf{W}_N \end{pmatrix}$ and

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

Equation (3.6) is then premultiplied by $\mathbf{G}_0^{-1}$, since $\mathbf{G}_0$ is a known non-singular matrix. The GVAR(2) model is

$$\mathbf{x}_t = \mathbf{b}_0 + \mathbf{b}_1 t + \mathbf{F}_1\mathbf{x}_{t-1} + \mathbf{F}_2\mathbf{x}_{t-2} + \boldsymbol{\varepsilon}_t, \tag{3.7}$$

where $\mathbf{b}_0 = \mathbf{G}_0^{-1}\mathbf{a}_0$, $\mathbf{b}_1 = \mathbf{G}_0^{-1}\mathbf{a}_1$, $\mathbf{F}_1 = \mathbf{G}_0^{-1}\mathbf{G}_1$, $\mathbf{F}_2 = \mathbf{G}_0^{-1}\mathbf{G}_2$ and $\boldsymbol{\varepsilon}_t = \mathbf{G}_0^{-1}\mathbf{u}_t$.

This model is solved recursively, usually with no restrictions on the covariance matrix $\boldsymbol{\Sigma}_\varepsilon = \mathbf{E}(\boldsymbol{\varepsilon}_t\boldsymbol{\varepsilon}_t')$. Due to the multivariate dynamics in the GVAR system, a small number of lags suffice. For quarterly data, two lags are the maximum number of lags necessary.

The linkages of the countries in the GVAR are through three channels: contemporaneous dependence of domestic variables ($\mathbf{x}_{it}$) on country-specific foreign variables ($\mathbf{x}_{it}^*$) and on lagged variables; dependence of domestic variables ($\mathbf{x}_{it}$) on common global variables ($\mathbf{d}_t$); and contemporaneous dependence of shocks ($\mathbf{u}_{it}$) across countries.

3.4. GVAR SPECIFICATION AND EMPIRICAL ESTIMATION

3.4.1 GVAR data

Table 3.1 GVAR variables

Variable	Description	Calculation
y_{it}	Domestic real GDP	*ln* real GDP for country *i* during period *t*

π_{it}	Domestic inflation	Quarterly inflation rate: first difference of *ln* CPI for country *i* at time *t*
q_{it}	Domestic real equity prices	*ln* real equity prices for country *i* at time *t*
ep_{it}	Domestic real exchange rates	*ln* nominal exchange rate in terms of US Dollars – *ln* CPI for country *i* at time *t*
ρ^{S}_{it}	Domestic short-term interest rates	0.25**ln*(1+short-term interest rate/100) for country *i* at time *t*
ρ^{L}_{it}	Domestic long-term interest rates	0.25**ln*(1+long-term interest rate/100) for country *i* at time *t*
y^{*}_{it}	Foreign real GDP	*ln* foreign real GDP for country *i* during period *t*
π^{*}_{it}	Foreign inflation	Quarterly foreign inflation rate: first difference of *ln* foreign CPI for country *i* at time *t*
q^{*}_{it}	Foreign real equity prices	*ln* foreign real equity prices for country *i* at time *t*
ep^{*}_{it}	Foreign real exchange rates	*ln* foreign nominal exchange rate in terms of US Dollar – *ln* foreign CPI for country *i* at time *t*
ρ^{S*}_{it}	Foreign short-term interest rates	0.25**ln*(1+foreign short-term interest rate/100) for country *i* at time *t*
ρ^{L*}_{it}	Foreign long-term interest rates	0.25**ln*(1+foreign long-term interest rate/100) for country *i* at time *t*
p^{oil}_{t}	Oil price	*ln* oil price at time *t*

Table 3.1 lists the GVAR variables, variable descriptions and calculation methods. Interest rates are adjusted from annual rates to quarterly rates, for comparison with the quarterly inflation rates. All the variables are used in natural logarithmic form. The country-specific foreign variables are calculated using three-year moving average trade shares to weigh the relevant foreign data.

Table 3.2 Average trade shares of countries in the GVAR with South Africa (2007 - 2009)

Country	Average trade share
China	13.69%
Germany	12.17%
United States	11.31%
Japan	9.23%
United Kingdom	7.67%
Saudi Arabia	3.99%
Spain	3.98%
Netherlands	3.68%
Italy	3.38%
India	3.15%
France	3.05%
Belgium	2.71%
Korea	2.46%
Australia	2.30%
Switzerland	2.19%
Brazil	1.93%

Country	Average trade share
Thailand	1.82%
Argentina	1.54%
Sweden	1.44%
Malaysia	1.35%
Turkey	1.23%
Canada	1.16%
Singapore	0.98%
Indonesia	0.85%
Austria	0.75%
Finland	0.62%
Mexico	0.41%
Norway	0.32%
New Zealand	0.22%
Philippines	0.16%
Chile	0.15%
Peru	0.10%
Total	**100.00%**
Euro area	**30.35%**

Source: '2009 Vintage' GVAR database (Smith & Galesi, 2011)

The model includes quarterly data for 33 countries (which include South Africa) from 1979Q2 to 2009Q4. The data for the GVAR model are from the '2009 Vintage' GVAR database (Smith & Galesi, 2011). Technical Appendix B of the GVAR Toolbox 1.1 User Guide by Smith and Galesi (2011) provides detailed information about the data sources and the methods of calculation of the data.

The average trade shares with South Africa between 2007 and 2009, of the 32 countries in the GVAR that represents South Africa's trading partners, are shown in Table 3.2. The Euro area in the GVAR includes Austria, Belgium, Finland, France, Germany, Italy, the Netherlands and Spain.

3.4.2 GVAR specification and estimation

The GVAR Toolbox 1.1 (Smith & Galesi, 2011) is used to specify and estimate the models. The eight countries in the GVAR dataset that are part of the Euro area (Austria, Belgium, Finland, France, Germany, Italy, the Netherlands and Spain) are combined into a single economy before estimation. The GVAR therefore includes 26 countries, with the Euro area being one of the economies.

To incorporate the major shift in international trade linkages, the study constructs the foreign-specific variables for each country using time-varying trade-weighted foreign variables. More specifically, three-year moving average trade weights are used to create the country-specific foreign variables. The final model specification is in line with that of Cesa-Bianchi *et al.* (2012). The GVAR is solved four times. Each of the solutions uses fixed trade shares in a different year to solve the model. The solution years are 1995, 2000, 2005 and 2009. It is then possible to investigate whether the impact of economic shocks in the rest of the world on South Africa changed over time due to the change in the key trading partners of South Africa and the change in international trade linkages.

For each country, depending on data availability, the domestic variables included are real GDP (y_{it}), inflation (π_{it}), real equity prices (q_{it}), real exchange rates ($ep_{it} = e_{it} - p_{it}$, i.e. nominal exchange rates minus domestic prices), short-term interest rates (ρ_{it}^{S}) and long-term interest rates (ρ_{it}^{L}). Country-specific foreign variables included for each country are foreign real GDP (y_{it}^{*}), foreign inflation (π_{it}^{*}), foreign real equity prices (q_{it}^{*}), foreign short-term interest rates (ρ_{it}^{S*}) and foreign long-term interest rates (ρ_{it}^{L*}). These foreign variables and the global variable, the oil price (p_t^{oil}), are weakly exogenous, as defined in Section 3.3.1, in the country models.

The US is the dominant country in the model; therefore, it has a different specification. Domestic GDP, inflation, real equity prices, short-term interest rates, long-term interest rates and the global oil price are endogenous in the US model. The weakly exogenous variables for the US are foreign GDP ($y_{US,t}^{*}$), foreign inflation ($\pi_{US,t}^{*}$), foreign exchange rates ($ep_{US,t}^{*} = e_{US,t}^{*} - p_{US,t}^{*}$) and foreign short-term interest rates ($\rho_{US,t}^{S*}$). Due to the importance of real equity prices and long-term interest rates of the US in foreign markets, these variables are not included as weakly exogenous in the US model. A compact representation of the variables in the GVAR is provided in Table 3.3.

Table 3.3 Variables included in the individual VARX* models

	All countries excluding US		US	
Variable	***Domestic***	***Foreign***	***Domestic***	***Foreign***
Real GDP	y_{it}	y_{it}^{*}	$y_{US,t}$	$y_{US,t}^{*}$
Inflation	π_{it}	π_{it}^{*}	$\pi_{US,t}$	$\pi_{US,t}^{*}$

Real equity prices	q_{it}	q_{it}^{*}	$q_{US,t}$	-
Real exchange rates	$ep_{it} = e_{it} - p_{it}$	-	-	$ep_{US,t}^{*} = e_{US,t}^{*} - p_{US,t}^{*}$
Short-term interest rates	ρ_{it}^{S}	ρ_{it}^{S*}	$\rho_{US,t}^{S}$	$\rho_{US,t}^{S*}$
Long-term interest rates	ρ_{it}^{L}	ρ_{it}^{L*}	$\rho_{US,t}^{L}$	-
Oil price	-	p_{t}^{oil}	p_{t}^{oil}	-

The Weighted-Symmetric Augmented Dickey Fuller (WS-ADF) unit root test is performed on all the variables. The WS-ADF results in Section B.1 in Appendix B indicate that the variables in the model are mostly $I(1)$, since in most cases the null hypothesis of a unit root (non-stationarity) cannot be rejected when the variables are tested in level form, while it is rejected when the variables are tested in first-differenced form. The study therefore assumes that all variables are $I(1)$ for the specification and estimation of the GVAR.

The AIC is used to select the lag order of the domestic variables (p_i) and the lag order of the foreign variables (q_i) for each of the country-specific VARX* models. A maximum lag order of two is allowed for p_i, but due to data limitations, a maximum lag order of one is allowed for q_i[6]. The AIC is preferred to the SBC for the selection of the lag orders, since the AIC tends to suggest more lags, thereby reducing serial correlation in the models. For most of the countries, a VARX*(2,1) specification is chosen, while a VARX*(1,1) specification is sufficient for Australia, China, Malaysia, Mexico and Singapore.

Table 3.4 Trace statistics at different rank orders for cointegration testing

Statistic	*Argentina*	*Australia*	*Brazil*	*Canada*	*Chile*	*China*	*Euro area*
# Domestic	5	6	4	6	5	4	6
# Foreign	6	6	6	6	6	6	6
$r = 0$	463.92†	346.99†	323.50†	267.86†	309.50†	164.88†	260.99†
$r = 1$	177.79†	238.33†	**79.77**	185.18†	195.00†	93.17†	184.31†
$r = 2$	85.46†	160.67†	27.76	121.47†	113.19†	**42.53**	**117.86**
$r = 3$	**27.10**	92.40†	9.60	**79.31**	58.36†	19.46	76.11
$r = 4$	12.17	**48.73**		47.45	**18.79**		42.97
$r = 5$		17.66		18.49			14.93

Statistic	*India*	*Indonesia*	*Japan*	*Korea*	*Malaysia*	*Mexico*	*New Zealand*
# Domestic	5	4	6	6	5	4	6
# Foreign	6	6	6	6	6	6	6
$r = 0$	198.45†	184.13†	281.53†	331.90†	184.51†	220.10†	372.98†
$r = 1$	128.08†	108.25†	179.38†	251.37†	**117.86**	112.25†	258.27†

[6] The order of the GVAR (p) is the maximum number of lags from p_i and q_i. For $p > 1$, as in the model considered in this chapter where $p = 2$, two conditions are imposed on q_i to avoid model instability given data limitations (Smith & Galesi, 2011). The conditions are $q_i \leq p - 1$ and $q_i \leq p_i$.

$r = 2$	**78.35**	**55.14**	122.16†	172.91†	65.44	58.50†	162.13†
$r = 3$	43.58	21.09	**72.12**	98.15†	29.89	**22.82**	**80.70**
$r = 4$	14.06		46.16	**49.84**	11.65		44.49
$r = 5$			21.45	21.30			21.82
Statistic	*Norway*	*Peru*	*Philippines*	*Saudi Arabia*	*Singapore*	*South Africa*	*Sweden*
# Domestic	6	4	5	3	5	6	6
# Foreign	6	6	6	6	6	6	6
$r = 0$	324.61†	324.37†	235.27†	132.99†	221.21†	256.73†	242.69†
$r = 1$	193.59†	136.16†	144.09†	70.50†	137.33†	172.69†	**153.24**
$r = 2$	**116.41**	66.59†	**68.04**	**23.82**	89.46†	**114.65**	99.14
$r = 3$	72.90	**16.03**	30.48		**52.21**	62.03	60.61
$r = 4$	30.75		7.42		17.91	35.16	33.79
$r = 5$	9.58					15.23	12.74
Statistic	*Switzerland*	*Thailand*	*Turkey*	*United Kingdom*	*United States*		
# Domestic	6	5	4	6	6		
# Foreign	6	6	6	6	4		
$r = 0$	263.17†	201.07†	148.50†	299.36†	273.46†		
$r = 1$	178.68†	129.14†	92.88†	175.62†	185.14†		
$r = 2$	**115.50**	**73.32**	**46.23**	120.40†	105.22†		
$r = 3$	70.20	43.06	15.67	**77.74**	**66.76**		
$r = 4$	37.04	18.39		37.70	29.77		
$r = 5$	13.01			15.61	11.81		

† Null hypothesis rejected at the 5% level of statistical significance.

Two tests are available to determine the number of cointegrating vectors (i.e. the rank of the cointegrating space) of each country model: the trace statistic and the maximum eigenvalue statistic for models with weakly exogenous $I(1)$ regressors proposed by Pesaran *et al.* (2000). The rank chosen by the trace statistic is used, since the trace test has higher power in smaller samples. Table 3.4 contains the trace statistics of Pesaran *et al.* (2000) for cointegration testing. The trace statistics in bold font indicate the first statistic for each country where the null hypothesis, that the rank is equal to r, cannot be rejected at a five per cent significance level, thereby showing the rank chosen by the trace statistic for each country.

Persistence profiles (PPs) illustrate the movements in the cointegrating vectors after a shock to the system. To show that the system will return to its long-run equilibrium following a system-wide shock, PPs should converge to zero in the long term. Generally, GVAR studies use a ten-year or 40-quarter period within which the PPs should converge to zero. Non-converging PPs are thought to be caused by some misspecification in the model (Smith, 2011). Reduced ranks are used for the countries that exhibit non-convergent PPs when using the original number of cointegrating relations chosen by the trace statistic for the country-specific VARX* models. In this model specification, rank reductions are as follows: from two to one (China, Euro area, India, Indonesia, Philippines, Saudi Arabia, South Africa and Thailand); from three to two (Mexico, New Zealand and the US); from three to one (Argentina, Canada, Japan, Peru, Singapore and the UK); from four to two (Australia and Chile); and from four to one (Korea).

Figure 3.2 Persistence profiles of key trading partners for selected cointegrating vectors

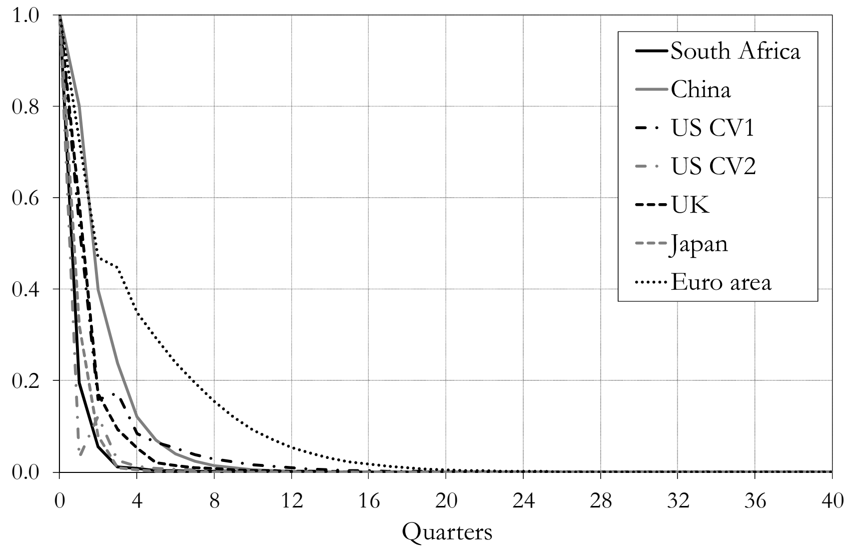


Figure 3.2 plots the PPs of the cointegrating vectors (CVs) of South Africa and its key trading partners, based on the final model specification and the GVAR solution in 2009. As with the PPs of the selected countries in Figure 3.2, the PPs of all the cointegrating vectors of all the countries in the GVAR converge to zero, thus the system will return to its long-run equilibrium after a system-wide shock to the cointegrating vectors.

A generalised impulse response function (GIRF) traces the effect over time of a one standard error or a one per cent shock to a specific variable in a specific country/region, on that variable and other variables of all the countries in the system. GIRFs should stabilise over time, since unstable GIRFs could point to instability due to misspecification in the GVAR (Smith, 2011). To achieve stable GIRFs in this GVAR, the domestic lags for Argentina, Brazil, Chile, India, Indonesia, New Zealand, Norway, Peru and Sweden are lowered from two to one, thus VARX*(1,1) specifications are chosen for these countries instead of the VARX*(2,1) specifications initially selected by the AIC.

In Section 3.3.1, the assumption of weak exogeneity of the foreign variables in the country specific VARX* models is explained. The weak exogeneity test is performed on all the foreign and global variables that are assumed to be weakly exogenous in the model specification. Di

Mauro and Smith (2013) describe the formal test of the assumption of weak exogeneity for the country-specific foreign variables ($\mathbf{x}_{it}^{*}$) and the global variable.

It is an F-test of the joint significance of the error-correction terms in auxiliary regressions for $\mathbf{x}_{it}^{*}$. Thus, the F-statistic for weak exogeneity tests the joint hypothesis that $\delta_{ij,\ell} = 0$ in the estimated auxiliary regression, for the ℓ th element of $\mathbf{x}_{it}^{*}$,

$$\Delta x_{it,\ell}^{*} = a_{i\ell} + \sum_{j=1}^{r_i} \delta_{ij,\ell} ECM_{ij,t-1} + \sum_{k=1}^{s_i} \boldsymbol{\phi}'_{ik,\ell} \Delta \mathbf{x}_{i,t-k} + \sum_{m=1}^{n_i} \boldsymbol{\psi}'_{im,\ell} \Delta \widetilde{\mathbf{x}}_{i,t-m}^{*} + \eta_{it,\ell} ,$$

where $\Delta\widetilde{\mathbf{x}}_{it}^{*} = \left(\Delta\mathbf{x}_{it}'^{*}, \Delta ep_{it}^{*}, \Delta p_t^{oil}\right)'$ for i = 1, 2, … , N. In the case of the US, $ep_{US,t}^{*}$ is included in $\Delta\widetilde{\mathbf{x}}_{it}^{*}$. $ECM_{ij,t-1}$ (j = 1, 2, … , r_i) are the estimated error-correction terms that matches the r_i long-run relations (rank) of the ith country. The lag orders for the lagged differenced domestic variables (s_i) and the lagged differenced foreign variables (n_i) respectively are set to p_i lags (see Table 3.6) and to two lags, in keeping with Cesa-Bianchi *et al.* (2012).

Table 3.5 displays the F-statistics of the weak exogeneity test. At a five per cent significance level, the null hypothesis of weak exogeneity is rejected for nine (i.e. six per cent) of the 154 variables. One expects to reject the null hypothesis incorrectly in around five per cent of cases, given the critical values at a five per cent level of significance. Thus, the weak exogeneity test results are satisfactory. Despite the large increase in the Chinese economy, the results suggest that the foreign variables in the VARX* model for China are consistent with the null hypothesis of weakly exogenous variables.

Table 3.5 Weak exogeneity test statistics

Country	*F-test*	y^*	π^*	q^*	ep^*	ρ^{S*}	ρ^{L*}	p^{oil}
Argentina	F(1,99)	3.79	0.00	2.25		0.35	0.36	0.07
Australia	F(2,97)	0.27	0.13	0.67		0.41	0.56	0.36
Brazil	F(1,100)	0.07	0.78	0.04		0.11	0.11	4.74†
Canada	F(1,92)	0.12	0.50	0.26		2.08	0.18	0.03
Chile	F(1,100)	0.06	0.02	0.03		0.90	3.81	1.65
China	F(2,98)	0.79	1.07	0.17		1.34	0.80	0.41
Euro area	F(1,92)	0.48	1.26	0.24		0.02	2.72	2.31
India	F(1,99)	0.09	0.06	0.51		0.32	0.03	2.85
Indonesia	F(1,100)	0.16	0.20	1.87		0.07	0.80	0.11
Japan	F(1,92)	0.04	1.24	0.25		4.44†	5.67†	3.18

Korea	F(1,92)	0.02	1.07	2.38		0.03	0.13	1.19
Malaysia	F(1,99)	2.94	3.66	5.28†		1.74	0.02	3.41
Mexico	F(2,99)	3.44†	0.31	1.03		1.27	1.59	0.05
New Zealand	F(2,97)	0.83	3.73†	0.16		1.83	0.76	3.81†
Norway	F(2,97)	2.29	1.54	0.16		0.09	0.15	1.08
Peru	F(1,100)	1.40	2.15	0.49		1.14	0.09	1.63
Philippines	F(1,94)	4.16†	1.80	1.43		0.00	0.25	4.01†
Saudi Arabia	F(1,92)	1.15	0.60	0.65		0.42	2.66	0.14
Singapore	F(1,98)	0.09	0.66	0.84		0.20	0.04	0.03
South Africa	F(1,99)	0.53	0.09	0.72		0.05	2.53	0.00
Sweden	F(1,98)	0.24	0.36	0.58		0.99	0.04	0.06
Switzerland	F(2,91)	2.08	0.58	2.03		0.12	0.51	0.07
Thailand	F(1,94)	0.01	0.72	0.01		0.01	0.04	0.45
Turkey	F(2,95)	0.68	1.70	0.02		2.92	0.15	0.45
United Kingdom	F(1,92)	0.10	0.89	1.00		0.76	0.00	2.04
United States	F(2,93)	0.65	0.06		0.45	2.12		

† Null hypothesis of weak exogeneity rejected at the 5% level of statistical significance.

The results of the parameter stability tests are summarised in Table B.4 in Section B.2 in Appendix B. The results are in line with the parameter stability results in Cesa-Bianchi *et al.* (2012).

Table 3.6 contains a summary of the final model specification, with the number of domestic lags (p_i), the number of foreign lags (q_i) and the number of cointegrating vectors (i.e. the rank) for each of the countries in the model. The specification is consistent with that of Cesa-Bianchi *et al.* (2012).

All the country-specific VECX* models are then estimated including an unrestricted intercept and a trend restricted to the cointegrating space. A trend is included in each model since the data are trended, but the coefficients of the trends are restricted to ensure that the solutions of the models in levels do not contain quadratic trends. After the estimation of the individual VECX* models, the GVAR is solved for 1995, 2000, 2005 and 2009.

Table 3.6 Individual VARX* specifications

Country	p_i	q_i	Rank	Country	p_i	q_i	Rank
Argentina	1	1	1	New Zealand	1	1	2
Australia	1	1	2	Norway	1	1	2
Brazil	1	1	1	Peru	1	1	1
Canada	2	1	1	Philippines	2	1	1
Chile	1	1	2	Saudi Arabia	2	1	1
China	1	1	1	Singapore	1	1	1
Euro area	2	1	1	South Africa	2	1	1

India	1	1	1	Sweden	1	1	1
Indonesia	1	1	1	Switzerland	2	1	2
Japan	2	1	1	Thailand	2	1	1
Korea	2	1	1	Turkey	2	1	2
Malaysia	1	1	1	United Kingdom	2	1	1
Mexico	1	1	2	United States	2	1	2

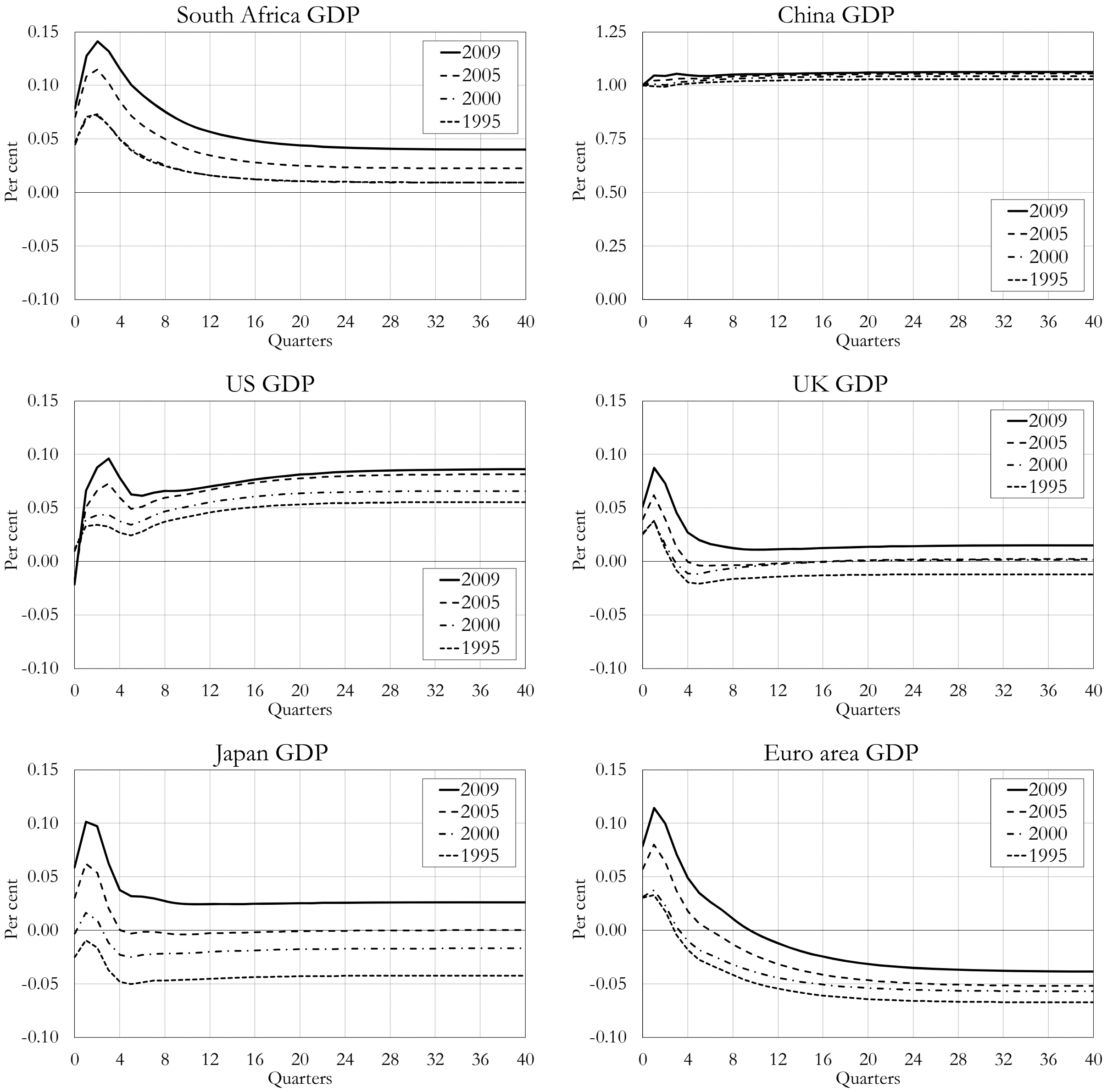
In the next section, the effect of shocks to GDP in China and the US on the GDP of South Africa and its main trading partners are analysed. These shocks cannot be interpreted as pure demand/supply or monetary policy shocks, since the GIRFs allow for correlation between the error terms ($\mathbf{u}$) in equation (3.6) in Section 3.3.2. To be able to investigate a pure monetary policy, demand or supply shock, the variance-covariance matrix of $\mathbf{u}$, i.e. $\mathbf{\Sigma_u}$, must include structural restrictions. As mentioned by Cesa-Bianchi *et al.* (2012) it is not necessary to impose structural restrictions to the shocks for this type of analysis, since the aim is to compare the effect of GDP shocks to specific economies on other economies at different points in time. The identification of the sources of the shocks, which would be possible by imposing structural restrictions, is not the focus of the study.

3.5. RESULTS OF SHOCKS TO THE GVAR

To investigate whether the impact of GDP shocks in the rest of the world on GDP in South Africa has changed over time, the GVAR is solved in four different years: 1995, 2000, 2005 and 2009. The effects of a one per cent GDP shock to China and a one per cent GDP shock to the US are then compared for the different years to quantify any differences (see Figure 3.3 and Figure 3.4). The study applies a shock to China's GDP, since the objective is to determine whether the substantial growth in trade between China and South Africa affects the transfer of shocks. The US is used as the reference country, since the US is often used in South African studies as a proxy for the rest of the world. Figure 3.1 also showed that trade between the US and South Africa declined noticeably since 1995.

First, the study investigates how the increase in China's importance in the world economy changes the transmission of GDP shocks from China to South Africa and its main trading partners. Figure 3.3 shows the GIRFs for a one per cent increase in Chinese GDP on GDP in South Africa, China, the US, the UK, Japan and the Euro area.

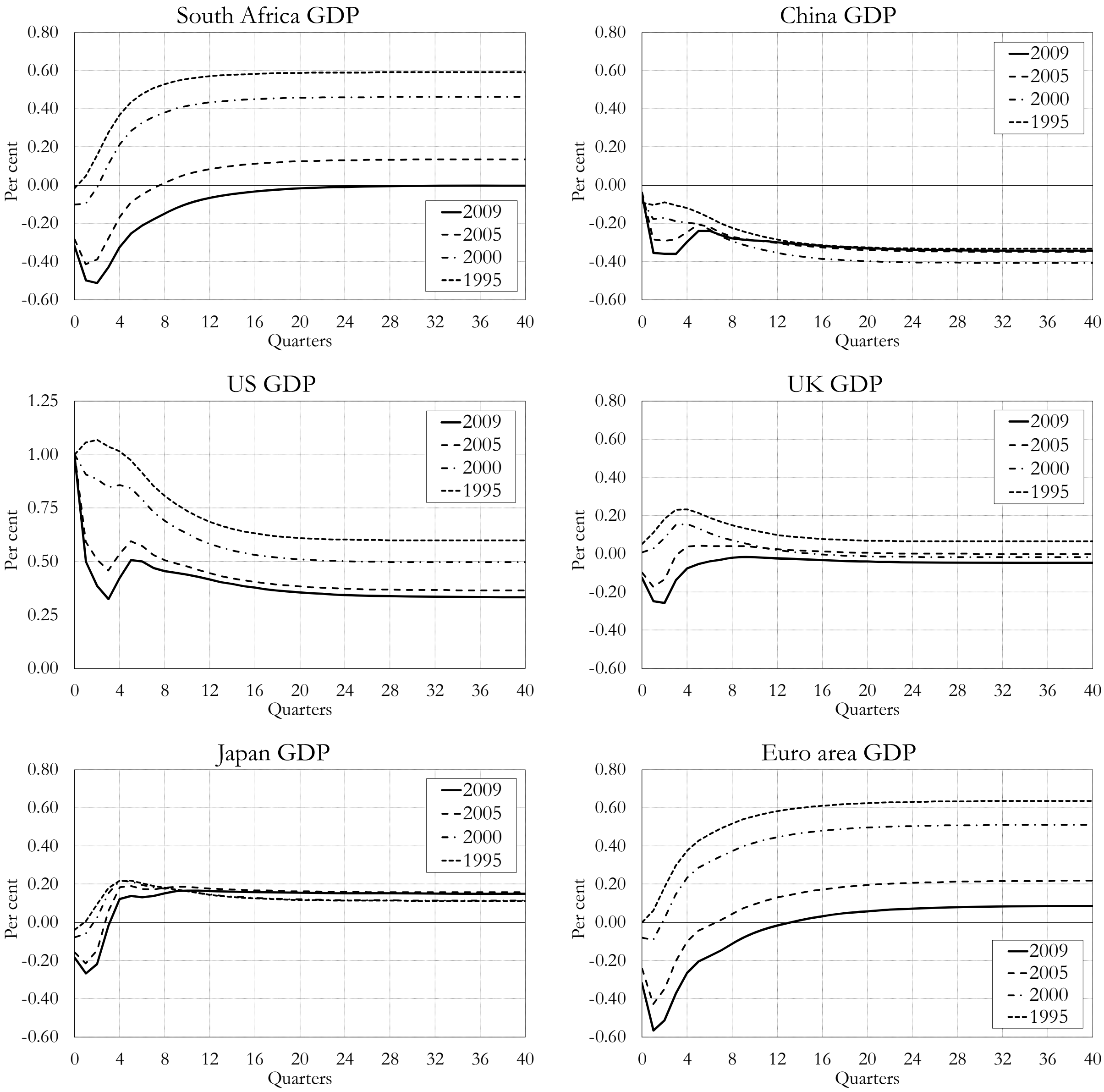
Figure 3.3 Generalised impulse response functions for a 1% increase in China GDP



The effects of a shock to Chinese GDP on the GDP of South Africa and its main trading partners have increased systematically and substantially since 1995. A numerical comparison of the long-term effects of a shock to Chinese GDP in 2009 to a shock in 1995, 2000 or 2005 confirms this. The long-term impact of a one per cent increase in Chinese GDP on South African GDP is 330 per cent stronger in 2009 than in 1995 and 2000, albeit off a low base, while the impact on US GDP is 55 per cent stronger compared to 1995 and 30 per cent stronger compared to 2000. The long-term effects of a Chinese GDP shock in 2009 on GDP in South Africa and the US respectively are 80 per cent and 6 per cent more than in 2005. A shock to GDP in China in 2009 also has higher impacts on GDP in the UK, Japan and the Euro area, in comparison to shocks in 1995, 2000 and 2005.

Figure B.1 and Figure B.2 in Section B.3 in Appendix B show the bootstrapped GIRFs for one standard deviation increases in China's GDP in 2009 and 1995 respectively, including 90% bootstrapped confidence intervals. Although the graphs in Figure B.1 indicate that the effects are mostly statistically insignificant in 2009, comparisons of the graphs with the graphs for 1995 in Figure B.2 show much smaller and more insignificant impacts in 1995 than in 2009. The effects of a Chinese GDP shock on GDP in South Africa and other countries are increasing over time.

Figure 3.4 Generalised impulse response functions for a 1% increase in US GDP



Second, the study determines the long-term effects of lower trade between South Africa and the US on the transfer of GDP shocks from the US to South Africa and its key trading partners. The results of a one per cent shock in US GDP are presented in Figure 3.4.

Due to the increase in China's importance in the world economy, relative to the US, a shock in US GDP in 2009 mostly has a lower impact on GDP in the other economies than a shock in 1995. For South Africa, the long-term impact of a one per cent shock in US GDP in 2005 was only a quarter of that of a similar shock in 1995. By 2009, the impact of a US GDP shock on South Africa is 100 per cent less than in 1995 and it is statistically insignificant. Due to changes in trade interdependencies, the effect of a shock to US GDP on US GDP itself has decreased since 1995, with the effect in 2009 only 56 per cent of that in 1995. In comparison with the transmission of a US GDP shock to the Euro area in 1995, the transmission is 20 per cent less in 2000, 66 per cent less in 2005 and 86 per cent less in 2009. The effect of a US GDP shock on Chinese GDP has not changed markedly over the long run. The changing impact on UK GDP and Japan GDP following a shock to US GDP is much larger in the short term than in the long term.

Figure B.3 and Figure B.4 in Section B.3 in Appendix B illustrate the GIRFs, with 90% bootstrapped confidence intervals, for one standard deviation increases in US GDP in 2009 and 1995 respectively. A comparison of the graphs for 2009 in Figure B.3 with the corresponding graphs for 1995 in Figure B.4 clearly show that the effect of a shock to the US economy on South Africa and the other illustrated economies are weakening over time. A shock to US GDP in 1995 had a statistically significant impact on South Africa, but a shock to US GDP in 2009 had a statistically insignificant effect on South Africa, since the impact is not statistically different from zero.

The graphs indicate that changes in the trade linkages of South Africa with China and the US have an influential impact on the transfer of GDP shocks between these countries and South Africa. This trend is not confined to South Africa. Due to China's emergence in the world economy, Chinese GDP shocks have a much larger impact than before, while the effect of US GDP shocks have declined.

3.6. CONCLUSION

The GVAR results confirm *a priori* expectations that the large changes in the trade shares of South Africa's trading patterns have a marked impact on the transmission of GDP shocks in China and the US on GDP in South Africa. South Africa did not trade with China before 1993, but due to the substantial growth in trade between the two countries, China has taken the position of its main trading partner on a country level. Trade with the US is much lower than in the 1990s. The long-term impact on South African GDP of a GDP shock in China in 2009 is more than 300 per cent higher in 2009 than in 1995, while the long-term impact of a US GDP shock on South African GDP in 2009 is a quarter of the impact in 2005. By 2009, the long-term impact of a US GDP shock on South African GDP compared to 1995 is insignificant. This explains why the recent global crisis did not affect South Africa as much as it affected developed economies.

The results indicate that a slowdown in economic growth in China could result in a marked slowdown in economic growth in South Africa and the rest of the world. Thus, policy makers in South Africa and the rest of the world should monitor the changing international trade linkages, especially since trade with China has increased further in the past few years. It is important for policy makers to consider the changes in global trade linkages and the resulting changes in the transmission of shocks during model building, forecasting and simulations of different scenarios; otherwise the results may be misleading.

CHAPTER 4

FORECASTING KEY SOUTH AFRICAN VARIABLES WITH A GLOBAL VAR MODEL

4.1. INTRODUCTION

Chapter 3 defines the GVAR approach to macroeconomic modelling as a multi-country approach, with a global trade matrix that links individual country models. By allowing for international trade linkages, it is possible to investigate the transmission of shocks from one country to another. Thus, GVAR forecasts of domestic and foreign variables allow for these global interaction channels. The research in this chapter determines whether it is necessary to use a GVAR model when forecasting key domestic variables for South Africa or whether a country-specific VECX* for South Africa would suffice.

The research furthermore establishes whether the GVAR model should include the standard 33 countries (Dées *et al.*, 2007a; Dées *et al.*, 2007b) or whether it could include only a small subset of countries – the most important trading partners of South Africa – when forecasting domestic variables. A smaller model could be simpler to specify and to update. One of the main findings of the GVAR studies highlighted in Di Mauro and Pesaran (2013) is that for small, open economies one could model only a few countries explicitly in the GVAR to get reliable forecasts. Assenmacher (2013) models only three trading partners together with Switzerland in a GVAR to forecast the Swiss economy. The statement that a small GVAR is sufficient for forecasting makes sense for Switzerland, since trade with the three included trading partners represents a substantial proportion (around 80 per cent) of Switzerland's trade with the countries in the 33-country GVAR. In the case of South Africa, trade with its three main trading partners represents only 55 per cent of trade with countries in the 33-country GVAR. Given the much smaller proportion of trade covered by the three main trading partners of South Africa, it is not clear *a priori* whether the forecasts of a small GVAR will be as reliable as forecasts of a large GVAR. It therefore justifies further investigation.

The main aim of this chapter is to investigate the forecast performance of GVAR models for the South African economy. As far as known, this is the first study for South Africa that evaluates the forecast performance of domestic variables with a GVAR model. The chapter also makes two contributions to the international literature. First, it compares the forecasting power of the standard 33-country GVAR and a customised small GVAR for South Africa to determine whether the key finding in Di Mauro and Pesaran (2013), as discussed in the previous paragraph, holds for a developing country like South Africa. Second, it uses the time-varying trade-weighted approach, rather than the fixed trade-weighted approach used in previous studies of GVAR forecasting, to account for the large changes in the trade weights of South Africa's trading partners over time.

The forecasts of key South African variables for five different models are compared. The first model is based on a standard 33-country GVAR (Cesa-Bianchi *et al.*, 2012), similar to the GVAR developed in Chapter 3. The second model is a small GVAR that is customised for South Africa, by only including models for South Africa and the three main trading partners of the country. The final model is a cointegrated VAR model with weakly exogenous foreign variables, known as an augmented VECM or VECX*, for South Africa. It is a simplified version, aligned with the GVAR models, of the VECX* for South Africa developed in Chapter 2. The fourth and fifth models are standard benchmark models used for forecast evaluation. These are univariate autoregressive (AR) and random walk (RW) models.

Recursive out-of-sample forecasts from one to eight quarters ahead for all the models are generated. A comparison of the root mean squared forecast errors (RMSFEs) of the models shows that the forecast errors of the 33-country GVAR are mostly smaller than the errors of the customised small GVAR for South Africa. The forecasts of both the GVAR models have smaller errors than the VECX* for South Africa over longer forecast horizons. The findings for South Africa are therefore only partly in line with the findings of Assenmacher (2013) for Switzerland, since the results do show the advantage of a GVAR model for forecasting, but it does not prove that a small GVAR is sufficient. It is not surprising that the forecasts of the large GVAR is better than that of the small GVAR for South Africa as trade with countries included in the small model only represent around 55 per cent of that of trade with trading partners included in the 33-country model. The results emphasise the importance of considering sufficient international trade linkages in macroeconomic modelling.

This chapter is structured as follows: Section 4.2 provides a summary of the GVAR forecasting literature, Section 4.3 includes the methodology of the VECX* and GVAR models, Section 4.4 comprise the model specifications, Section 4.5 shows the forecasting results and Section 4.6 concludes.

4.2. LITERATURE REVIEW

The literature contains ample studies that evaluate the forecast performance of different models for forecasting the South African economy. Models evaluated for forecast accuracy include VAR, VECM, Bayesian VAR (BVAR) and Bayesian VECM (BVECM) models (Gupta & Sichei, 2006; Gupta, 2006; 2007). Gupta and Kabundi (2010; 2011) investigate large-scale Factor Models (FMs) for forecast performance, while Ngoie and Zellner (2012) illustrate the forecasting power of a disaggregated Marshallian macroeconomic model. DSGE models used for forecasting include various closed-economy DSGE models (Liu & Gupta, 2007; Liu, Gupta & Schaling, 2009; 2010), small open economy New Keynesian DSGE models (Steinbach *et al.*, 2009; Alpanda, Kotzé & Woglom, 2011), a small open economy New Keynesian DSGE-VAR model (Gupta & Steinbach, 2013) and a recent closed-economy nonlinear DSGE model (Balcilar, Gupta & Kotzé, 2013).

Some of these models contain only data for South Africa, while the other models incorporate the rest of the world by using the US as a proxy or by including aggregate fixed trade-weighted foreign variables. The FMs include some global series and variables for selected major trading partners (Germany, the UK and the US). None of these models includes time-varying trade-weighted foreign variables to take into account the major change in the trade shares of South Africa's main trading partners since the mid-1990s.

As far as I know, no literature exists on forecasting domestic variables for South Africa with a GVAR model and for comparing the forecasts with those from a VECM model augmented with foreign variables, named a VECX*, for South Africa. This is the aim of this research.

The power of GVAR models for forecasting global variables is evident from the literature. In the first GVAR forecasting application, Pesaran *et al.* (2009a; 2009b) forecast macroeconomic and financial variables for all 26 regions in the standard 33-country GVAR of Dées *et al.* (2007a; 2007b). Their study considers short-term (one quarter in advance) and medium-term (four quarters in advance) out-of-sample forecasts. The results show that double-averaged (AveAve) GVAR forecasts, i.e. average forecasts across different GVAR specifications and different estimation windows, generally perform better than benchmark forecasts from univariate autoregressive and random walk models as well as forecasts from individual GVAR models. Smith (2013a) summarises the conclusions of Pesaran *et al.* (2009a) and reinforces the findings by adding out-of-sample data for another four quarters before re-evaluating the models.

In most of the GVAR forecasting literature, the aim is to forecast variables for all countries in the GVAR or for the main countries in the GVAR. Studies often focus on the assessment of 'pooling' methods, such as averaging forecasts over different sample periods, to find the 'pooling' method that performs best in forecasting (Assenmacher-Wesche & Geissmann, 2013). Eickmeier and Ng (2011) investigate various weighting structures for the foreign financial variables in the GVAR, for instance the use of inward foreign direct investment weights rather than trade weights, to find the financial weighting scheme with the lowest forecast errors.

The GVAR approach is also a useful tool for nowcasting and for scenario-based forecasting with density forecasts and/or probabilistic forecasts. To nowcast aggregate Euro area GDP growth at a shorter time lag (30 days) than that of the official estimate (45 days), Lui and Mitchell (2013) use a GVAR model with data for all the Euro area countries. Garratt *et al.* (2013) develop a GVAR of actual and expected output for the G7 countries (Canada, France, Germany, Italy, Japan, the UK and the US) that produces reasonable nowcasts of the probability of negative GDP growth in the current period, which could assist policy makers with the early identification of recessions. Greenwood-Nimmo *et al.* (2012; 2013) illustrate the effective utilisation of the GVAR approach for scenario-based probabilistic forecasting of macroeconomic variables. Probabilistic forecasts can be determined for single scenarios or for joint scenarios.

Section 4.1 referred to the GVAR forecasting study most relevant to this research, which proves the forecasting power of a small GVAR for Switzerland compared to simpler forecasting models (Assenmacher, 2013). The small Swiss GVAR includes models for Switzerland and three large trading partners: the Euro area, the US and Japan. The Euro area and the US are the two largest trading partners of Switzerland, while Japan is its largest trading partner in Asia. Forecasts of Swiss CPI and GDP from the small GVAR are compared to forecasts from a VECX* model for Switzerland. The study finds that the forecasting performance of the small GVAR is superior to that of the VECX*.

The three trading partners in the small GVAR for Switzerland account for 80 per cent of Switzerland's average trade between 2007 and 2009 with the countries included in the 33-country GVAR (82 per cent between 2002 and 2004). In the case of South Africa, the three main trading partners of South Africa are the Euro area, China and the US. However, since South Africa's trade with the rest of the world is quite diverse, trade with these countries only represents 55 per cent of South Africa's average trade covered by the 33-country GVAR from 2007 to 2009 (55 per cent from 2002 to 2004). As mentioned in Section 4.1, it is not evident that a small GVAR will be sufficient for South Africa, due to the far lower percentage of trade covered by its three main trading partners compared to the percentage of trade covered by the three trading partners in the small GVAR for Switzerland.

The study loosely follows the approach of Assenmacher (2013), which is a summary of the research in Assenmacher-Wesche and Geissmann (2013), but I tailor it for South Africa. An addition in this study is the comparison of forecasts from both a large GVAR, with 33 countries (26 regions when the Euro area countries are grouped together), and a customised small GVAR for South Africa, with eleven countries (four regions when the Euro area countries are combined). This enables the comparison of forecasts of a large GVAR with those of a small GVAR for South Africa.

Due to large shifts in the trade weights of South Africa's trading partners over the past two decades, time-varying trade-weighted approach are used to create the foreign data for estimating and solving the models, rather than the fixed trade-weighted approach followed by Assenmacher (2013). For forecasting, the trade weights are assumed to remain constant at the last available values at the time of the model estimation.

4.3. METHODOLOGY

Section 4.3.1 describes the methodology for building a country-specific VECX* model, such as the South African VECX* developed in Chapter 2 and the simpler version in this study. Section 4.3.2 discusses the methodology for building GVAR models, like the GVAR used in Chapter 3 and the GVAR models in this chapter. A GVAR model includes country-specific VECX* models for each of the countries in the global model, thus the GVAR methodology builds on the VECX* methodology. I use the explanation and notation of Di Mauro and Smith (2013). Although Section 4.3 is largely a repetition of the methodology described in Section 3.3, the information is included again in this chapter for clarity and completeness.

4.3.1 Country-specific VECX* model

Garratt *et al.* (2006) document the VECX* approach in detail. An overview of the approach is provided, based on Di Mauro and Smith (2013).

A VARX*(p, q) model is a VAR model with weakly exogenous (X) foreign (*) variables. The lag orders of the domestic and foreign variables, respectively p and q, are selected using the AIC or the SBC. Suppose p and q are both two. The VARX*(2,2) structure, including a constant and a trend is:

$$\mathbf{x}_t = \mathbf{a}_0 + \mathbf{a}_1 t + \mathbf{\Phi}_1 \mathbf{x}_{t-1} + \mathbf{\Phi}_2 \mathbf{x}_{t-2} + \mathbf{\Lambda}_0 \mathbf{x}_t^* + \mathbf{\Lambda}_1 \mathbf{x}_{t-1}^* + \mathbf{\Lambda}_2 \mathbf{x}_{t-2}^* + \mathbf{u}_t , \quad (4.1)$$

where $t = 1, 2, \dots , T$ represents the time periods, $\mathbf{x}_t$ is a $k \times 1$ vector of domestic $I(1)$ variables, $\mathbf{x}_t^*$ is a $k^* \times 1$ vector of country-specific foreign $I(1)$ variables and $\mathbf{u}_t$ is a process with no serial correlation.

To compute the foreign variables ($\mathbf{x}_t^*$), fixed or time-varying trade weights are used to combine the relevant data of the foreign countries ($j = 0, 1, 2, \dots , N$) using the formula

$$\mathbf{x}_t^* = \sum_{j=0}^{N} w_j \mathbf{x}_{jt} , \quad (4.2)$$

where w_j is the trade share of country j in the trade (average of exports and imports) of the domestic country. The trade share of the domestic country with itself is zero and the trade shares of the foreign countries with the domestic country sum to one (100 per cent).

The domestic variables ($\mathbf{x}_t$) are endogenous, while the foreign variables ($\mathbf{x}_t^*$) are assumed to be weakly exogenous (long-run forcing for the domestic variables) in the VECX*. This means that foreign variables do affect domestic variables in the long run, but the opposite is not true, hence domestic variables cannot affect foreign variables in the long run. This assumption is sensible for small open economies, such as South Africa.

The number of cointegrating relations, known as the rank, of the VARX* in equation (4.1) is selected based on the trace statistic. A potential VECX* for equation (4.1) is

$$\Delta \mathbf{x}_t = \mathbf{c}_0 - \alpha \beta' \left[\mathbf{z}_{t-1} - \gamma (t-1) \right] + \mathbf{\Lambda}_0 \Delta \mathbf{x}_t^* + \Gamma \Delta \mathbf{z}_{t-1} + \mathbf{u}_t , \quad (4.3)$$

with $\mathbf{z}_t = (\mathbf{x}'_t, \mathbf{x}'^*_t)'$, $\boldsymbol{\alpha}$ a $k \times r$ matrix with the speed of adjustment coefficients and $\boldsymbol{\beta}$ a $(k + k^*) \times r$ matrix with the cointegrating vectors. Using $\boldsymbol{\beta} = (\boldsymbol{\beta}'_x, \boldsymbol{\beta}'_{x^*})'$, the r error-correction terms of equation (4.3) can be rewritten as

$$\boldsymbol{\beta}'(\mathbf{z}_t - \boldsymbol{\gamma} t) = \boldsymbol{\beta}'_x \mathbf{x}_t + \boldsymbol{\beta}'_{x^*} \mathbf{x}^*_t - (\boldsymbol{\beta}' \boldsymbol{\gamma}) t . \tag{4.4}$$

The long-run multiplier matrix of a normal VECM is $\boldsymbol{\alpha\beta}' = \mathbf{\Pi}$. However, the foreign variables are assumed weakly exogenous or long-run forcing for the domestic variables. If $\mathbf{\Pi}$ is separated as $\mathbf{\Pi}' = (\mathbf{\Pi}'_x, \mathbf{\Pi}'_{x^*})$, the weak exogeneity assumption implies that $\mathbf{\Pi}_{x^*} = 0$. As a result the long-run multiplier matrix of the VECX* in equation (4.3) is $\boldsymbol{\alpha\beta}' = \mathbf{\Pi}_x$. This further signifies that the marginal or sub-system VECM for the weakly exogenous foreign variables does not contain the cointegrating vectors of the overall VECX* model since $\mathbf{\Pi}_{x^*} = 0$ (Pesaran *et al.*, 2000). Equation (4.5) shows the marginal equations for the foreign variables:

$$\Delta \mathbf{x}^*_t = \sum_{i=1}^{p-1} \mathbf{\Gamma}_{x^* i} \Delta \mathbf{z}_{t-i} + \mathbf{a}_{x^* 0} + \mathbf{u}_{x^* t} . \tag{4.5}$$

4.3.2 GVAR model

This section contains a brief description of the GVAR model developed by Pesaran *et al.* (2004), Garratt *et al.* (2006), Pesaran and Smith (2006), and Dées *et al* (2007a; 2007b).

In a GVAR system, the domestic and foreign variables are determined endogenously. A GVAR therefore includes country-specific VECX* models for each of the countries (i = 0, 1, 2, … , N) in the global model, with country 0 the reference country. The N + 1 individual VECX* models are all estimated over the time period t = 1, 2, … , T.

The approach described in Section 4.3.1 is used to develop each of these county-specific models, with $\mathbf{x}_{it}$ a $k_i \times 1$ vector of endogenous I(1) domestic variables and $\mathbf{x}^*_{it}$ a $k^*_i \times 1$ vector of weakly exogenous I(1) foreign variables. The number of domestic and foreign variables (k_i and k^*_i) can differ across countries. Global variables (e.g. the oil price) are endogenous in the model of the dominant country, but weakly exogenous in all the other country models. The dominant or reference country in the GVAR is the US since it dominates global financial markets.

The foreign variables ($\mathbf{x}_{it}^*$) for each country i are calculated from the domestic variables of the other countries in the system:

$$\mathbf{x}_{it}^* = \sum_{j=0}^{N} w_{ij} \mathbf{x}_{jt} , \tag{4.6}$$

where w_{ij} are fixed or time-varying trade weights that reflect the trade share of country j (with j = 0, 1, 2, … , N) in the trade (average of exports and imports) of country i. The predetermined weights satisfy the conditions $w_{ii} = 0$ and $\sum_{j=0}^{N} w_{ij} = 1$.

The 'curse of dimensionality' associated with VAR models is avoided due to the weak exogeneity assumption, which allows for the estimation of individual VECX* models for all the countries before solving the GVAR to obtain all the endogenous variables ($k = \sum_{i=0}^{N} k_i$).

To derive the GVAR solution, the VARX*(2,2) from equation (4.1) is written as

$$\mathbf{A}_{i0}\mathbf{z}_{it} = \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \mathbf{A}_{i1}\mathbf{z}_{i,t-1} + \mathbf{A}_{i2}\mathbf{z}_{i,t-2} + \mathbf{u}_{it} , \tag{4.7}$$

where i = 0, 1, 2, … , N represent the N + 1 countries, $\mathbf{z}_{it} = \left(\mathbf{x}_{it}', \mathbf{x}_{it}'^*\right)'$, $\mathbf{A}_{i0} = \left(\mathbf{I}_{ki}, -\mathbf{\Lambda}_{i0}\right)$, $\mathbf{A}_{i1} = \left(\mathbf{\Phi}_{i1}, \mathbf{\Lambda}_{i1}\right)$ and $\mathbf{A}_{i2} = \left(\mathbf{\Phi}_{i2}, \mathbf{\Lambda}_{i2}\right)$.

Equation (4.7) is rewritten as

$$\mathbf{A}_{i0}\mathbf{W}_i\mathbf{x}_t = \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \mathbf{A}_{i1}\mathbf{W}_i\mathbf{x}_{t-1} + \mathbf{A}_{i2}\mathbf{W}_i\mathbf{x}_{t-2} + \mathbf{u}_{it} , \tag{4.8}$$

by means of the identity $\mathbf{z}_{it} = \mathbf{W}_i\mathbf{x}_t$, where $\mathbf{x}_t = \left(\mathbf{x}_{0t}', \mathbf{x}_{1t}', \ldots, \mathbf{x}_{Nt}'\right)'$ is a $k \times 1$ vector of endogenous variables and $\mathbf{W}_i$ is a $\left(k_i + k_i^*\right) \times k$ trade link matrix based on the country-specific trade weights w_{ij}.

The individual country models from equation (4.8) are stacked to get a model of the endogenous variables $\mathbf{x}_t$:

$$\mathbf{G}_0\mathbf{x}_t = \mathbf{a}_0 + \mathbf{a}_1 t + \mathbf{G}_1\mathbf{x}_{t-1} + \mathbf{G}_2\mathbf{x}_{t-2} + \mathbf{u}_t, \tag{4.9}$$

where $\mathbf{G}_0 = \begin{pmatrix} \mathbf{A}_{00}\mathbf{W}_0 \\ \mathbf{A}_{10}\mathbf{W}_1 \\ \vdots \\ \mathbf{A}_{N0}\mathbf{W}_N \end{pmatrix}$, $\mathbf{a}_0 = \begin{pmatrix} \mathbf{a}_{00} \\ \mathbf{a}_{10} \\ \vdots \\ \mathbf{a}_{N0} \end{pmatrix}$, $\mathbf{a}_1 = \begin{pmatrix} \mathbf{a}_{01} \\ \mathbf{a}_{11} \\ \vdots \\ \mathbf{a}_{N1} \end{pmatrix}$, $\mathbf{G}_1 = \begin{pmatrix} \mathbf{A}_{01}\mathbf{W}_0 \\ \mathbf{A}_{11}\mathbf{W}_1 \\ \vdots \\ \mathbf{A}_{N1}\mathbf{W}_N \end{pmatrix}$, $\mathbf{G}_2 = \begin{pmatrix} \mathbf{A}_{02}\mathbf{W}_0 \\ \mathbf{A}_{12}\mathbf{W}_1 \\ \vdots \\ \mathbf{A}_{N2}\mathbf{W}_N \end{pmatrix}$ and

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

$\mathbf{G}_0$ is a known non-singular matrix. As a result, equation (4.9) can be premultiplied by $\mathbf{G}_0^{-1}$ to obtain the final GVAR(2) model:

$$\mathbf{x}_t = \mathbf{b}_0 + \mathbf{b}_1 t + \mathbf{F}_1\mathbf{x}_{t-1} + \mathbf{F}_2\mathbf{x}_{t-2} + \boldsymbol{\varepsilon}_t, \tag{4.10}$$

where $\mathbf{b}_0 = \mathbf{G}_0^{-1}\mathbf{a}_0$, $\mathbf{b}_1 = \mathbf{G}_0^{-1}\mathbf{a}_1$, $\mathbf{F}_1 = \mathbf{G}_0^{-1}\mathbf{G}_1$, $\mathbf{F}_2 = \mathbf{G}_0^{-1}\mathbf{G}_2$ and $\boldsymbol{\varepsilon}_t = \mathbf{G}_0^{-1}\mathbf{u}_t$.

Equation (4.10) is solved recursively, normally without restrictions on the covariance matrix of the error terms ($\boldsymbol{\Sigma}_\varepsilon = \mathbf{E}(\boldsymbol{\varepsilon}_t\boldsymbol{\varepsilon}_t')$)

4.4. MODEL SPECIFICATIONS

The data for all the models are from the '2009 Vintage' GVAR database of the GVAR Toolbox 1.1 (Smith & Galesi, 2011), which contains data from 1979Q2 to 2009Q4 for 33 countries that account for around 90 per cent of world output. Technical Appendix B of the GVAR Toolbox 1.1 User Guide, compiled by Smith and Galesi (2011), provides detailed information about the data and the data sources.

The country-specific foreign variables for the relevant models are created with three-year moving-average trade-weighted data of the relevant countries.

Data from 1979Q2 to 2004Q4 represent the in-sample period, while the out-of-sample forecast period is from 2005Q1 to 2009Q4. For the initial in-sample solution, three-year moving-average trade weights up to 2004Q4 are used for the estimations of the individual country models. For the GVAR, 2004 is used to solve the model (based on average trade weights between 2002 and 2004) to get the out-of-sample forecasts for one up to eight quarters ahead. For the recursive estimations from 2005Q1 to 2009Q4, the in-sample period is brought ahead by a quarter every time. For each re-estimation, the individual country models are estimated with an additional quarter of data based on three-year moving average trade weights. For the GVAR, the solution date for the forecasts, based on the updated data and individual country models, is only extended when new annual trade weights would have been available. For example, for the recursive estimations from 2005Q1 to 2005Q4, the GVAR model is still solved for 2004 (average trade weights between 2002 and 2004) to get the recursive forecasts based on the updated variables and updated individual country models. However, for the GVAR solutions in all the quarters in 2006, the updated country-specific models and the average trade weights between 2003 and 2005 determine the solution and the forecasts, while for the 2009 solutions and forecasts, the updated data together with the average trade weights between 2006 and 2008 determine the solution.

4.4.1 GVAR models

Two GVAR models are estimated using data from 1979Q1 to 2004Q4. The recursive out-of-sample forecasts up to eight quarters ahead are then compared with the actual data from 2005Q1 to 2009Q4. Although a longer out-of-sample period could provide better statistics for forecast evaluation, a shorter in-sample period does not fully incorporate the changes in global trade linkages in the model specification and solution.

First, a 33-country GVAR, referred to as the 'large GVAR', is estimated. Since the eight Euro area countries from the GVAR database are grouped into a region, it is effectively a 26-region GVAR. The Euro area countries include Austria, Belgium, Finland, France, Germany, Italy, the Netherlands and Spain. The study considers the model specification of Cesa-Bianchi *et al.* (2012), which was also used in Chapter 3, but due to the different estimation period (up to 2004Q4 and not 2009Q4); the specification is adjusted to result in a stable model.

Second, a customised small GVAR model for South Africa, referred to as the 'small GVAR', is estimated. The customised model only includes data for South Africa and its three main trading partners. The highest average trade weights from 2005 to 2009 determine the key trading partners. These trading partners are the Euro area, China and the US. The GVAR thus includes four regions with 11 countries: South Africa, China, the US and the eight Euro area countries.

The foreign variables of the large and small GVARs are not the same. For the countries of each model, the foreign variables are calculated by weighting the foreign data of the countries in the specific GVAR with the relevant three-year moving-average trade shares of those countries.

Table 4.1 summarises the variables that are included in the country-specific VARX* models of the large (26-region) and small (four-region) GVARs.

Table 4.1 Variables included in the country-specific VARX* models of the GVARs[7]

	All countries excluding US		US	
Variable	***Domestic***	***Foreign***	***Domestic***	***Foreign***
Real GDP	y_{it}	y_{it}^{*}	$y_{US,t}$	$y_{US,t}^{*}$
Inflation	π_{it}	π_{it}^{*}	$\pi_{US,t}$	$\pi_{US,t}^{*}$
Real exchange rates	$ep_{it} = e_{it} - p_{it}$	-	-	$ep_{US,t}^{*} = e_{US,t}^{*} - p_{US,t}^{*}$
Short-term interest rates	ρ_{it}^{S}	ρ_{it}^{S*}	$\rho_{US,t}^{S}$	$\rho_{US,t}^{S*}$
Long-term interest rates	ρ_{it}^{L}	ρ_{it}^{L*}	$\rho_{US,t}^{L}$	-
Oil price	-	p_t^{oil}	p_t^{oil}	-

The domestic variables are real GDP (y_{it}), inflation (π_{it}), real exchange rates (ep_{it}), short-term interest rates (ρ_{it}^{S}) and long-term interest rates (ρ_{it}^{L}). Real exchange rates are nominal exchange rates minus domestic prices ($ep_{it} = e_{it} - p_{it}$). The foreign variables that are calculated for each country, and for each model, include foreign real GDP (y_{it}^{*}), foreign inflation (π_{it}^{*}), foreign short-term interest rates (ρ_{it}^{S*}) and foreign long-term interest rates (ρ_{it}^{L*}). The global variable, the oil price (p_t^{oil}), is added as weakly exogenous in all country VARX* models except for the US VARX* model.

[7] The WS-ADF unit root test results show that most of the variables are $I(1)$. In line with previous GVAR studies, this study therefore assumes that all the variables are $I(1)$. The unit root test results are not included, since the outcomes are generally the same as that of the GVAR for the full sample period. The results of the unit root tests for the full sample period are included in Section B.1 in Appendix B.

The US specification differs from that of the other countries, since it is the dominant country in the model. The domestic (endogenous) variables for the US are GDP, inflation, short-term interest rates, long-term interest rates and the oil price. The foreign (weakly exogenous) variables for the US are foreign GDP ($y^{*}_{US,t}$), foreign inflation ($\pi^{*}_{US,t}$), foreign exchange rates ($ep^{*}_{US,t}$) and foreign short-term interest rates ($\rho^{S*}_{US,t}$). The foreign long-term interest rate of the US cannot be included, as it is not weakly exogenous in the US VARX* due to the prominence of the US bond market in global financial markets.

For the preliminary specification of country-specific VARX* models in the large GVAR, the AIC determines the number of lags for the domestic variables (p_i) and the number of lags for the foreign variables (q_i) for the individual VARX* models. Maximum lag orders of respectively two and one are considered for p_i and q_i. The rank (i.e. the number of cointegrating vectors) for each of the country models is chosen from the trace statistics.

Table 4.2 Trace statistics at different rank orders for cointegration testing for large GVAR

Statistic	*Argentina*	*Australia*	*Brazil*	*Canada*	*Chile*	*China*	*Euro area*
# Domestic	4	5	4	5	4	4	5
# Foreign	5	5	5	5	5	5	5
$r = 0$	132.54†	163.83†	139.51†	219.24†	182.96†	133.31†	155.60†
$r = 1$	**67.10**	113.04†	**64.61**	133.06†	94.65†	**76.75**	**99.57**
$r = 2$	31.90	**63.84**	26.46	85.28†	**39.53**	42.61	54.35
$r = 3$	6.83	39.51	10.03	**43.24**	9.25	17.03	28.86
$r = 4$		16.59		12.90			7.75
Statistic	*India*	*Indonesia*	*Japan*	*Korea*	*Malaysia*	*Mexico*	*New Zealand*
# Domestic	4	4	5	5	4	4	5
# Foreign	5	5	5	5	5	5	5
$r = 0$	129.91†	149.04†	205.63†	242.40†	**100.73**	168.57†	197.06†
$r = 1$	**76.35**	82.99†	127.37†	164.08†	61.11	81.61†	122.03†
$r = 2$	43.22	**37.68**	**73.31**	93.85†	26.41	**45.09**	**73.31**
$r = 3$	15.68	16.14	41.84	**41.64**	8.18	18.27	39.26
$r = 4$			14.29	12.44			15.61
Statistic	*Norway*	*Peru*	*Philippines*	*Saudi Arabia*	*Singapore*	*South Africa*	*Sweden*
# Domestic	5	4	4	3	4	5	5
# Foreign	5	5	5	5	5	5	5
$r = 0$	173.49†	170.29†	160.97†	120.99†	161.07†	172.57†	173.03†
$r = 1$	113.28†	106.52†	81.81†	58.44†	83.97†	111.90†	117.16†
$r = 2$	**61.89**	54.24†	**23.72**	**24.86**	**45.06**	**61.91**	**66.91**
$r = 3$	25.48	**16.10**	8.03		15.56	29.32	29.71
$r = 4$	5.95					8.39	9.89
Statistic	*Switzerland*	*Thailand*	*Turkey*	*United Kingdom*	*United States*		
# Domestic	5	4	4	5	5		

# Foreign	5	5	5	5	4
r = 0	195.91†	165.66†	113.40†	209.72†	209.42†
r = 1	115.98†	97.30†	**66.68**	114.55†	119.05†
r = 2	**61.18**	**49.88**	34.07	**68.10**	**65.51**
r = 3	32.52	12.95	10.65	36.76	39.14
r = 4	9.82			11.23	16.20

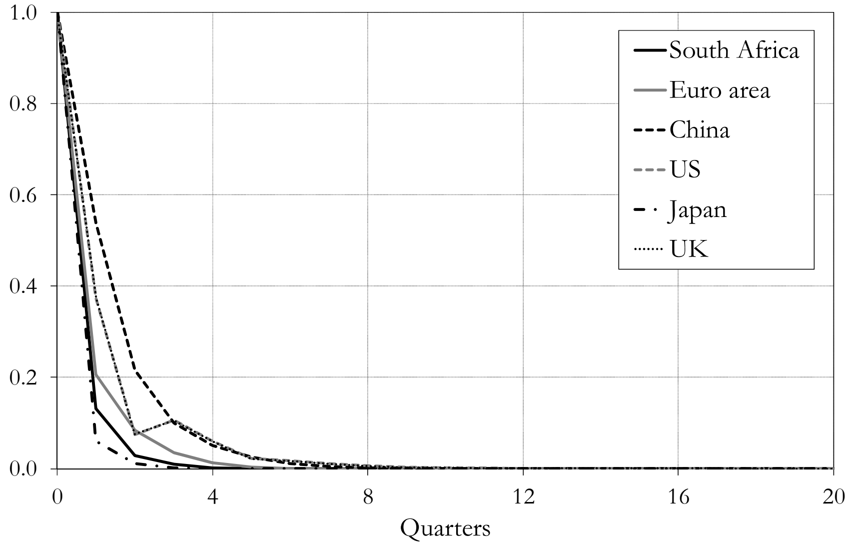
† Null hypothesis (rank = r) rejected at the 5% level of statistical significance.

Table 4.2 contains the trace statistics for determining the number of cointegrating relations for the countries in the large GVAR. The trace statistics in bold font – the first statistic for each country where the null hypothesis (rank = *r*) cannot be rejected – indicate the initial ranks chosen.

To determine whether the model is stable based on the preliminary specification, the persistence profiles and generalised impulse response functions are analysed. Persistence profiles (PPs) trace the effects over time of a system shock on all the cointegrating vectors in the GVAR. PPs should converge to zero to indicate a return to the long-run equilibrium. If a PP does not converge to zero, the related vector is not a cointegrating vector. The ranks chosen by the trace statistics are reduced for countries with non-converging PPs. For the final model specification of the large GVAR, the reductions in the number of cointegrating vectors are as follows: from three to one (Canada, Korea and Peru) and from two to one (Indonesia, Japan, New Zealand, Philippines, Saudi Arabia, Singapore, South Africa, Thailand, UK and US).

Figure 4.1 illustrates the PPs for a selection of cointegrating vectors of South Africa and its key trading partners from the final specification of the large GVAR. The PPs of the selected cointegrating vectors converge to zero at a fast rate, indicating that the system will return to the long-run equilibrium following a shock to all the cointegrating vectors. The PPs of the other cointegrating vectors in the large GVAR all converge within a maximum of 10 quarters, thus indicating a quick recovery.

Figure 4.1 Persistence profiles of cointegrating vectors of South Africa's key trading partners in the large GVAR



Generalised impulse response functions (GIRFs) plot the impact over time of a one standard error shock to specific variables on all the variables in the system. If GIRFs do not stabilise over time, there could be misspecification in the GVAR (Smith, 2011). To avoid volatile and unstable GIRFs, the number of domestic lags for Argentina, Malaysia, Norway and Sweden are reduced from two to one. Malaysia initially had no cointegrating vectors in its country model, but after the increase in the number of domestic lags for Malaysia, the rank changed to one.

Weak exogeneity tests on the foreign and global variables in the country-specific VARX* models of the large GVAR support the assumption of weak exogeneity, since the null hypothesis of weak exogeneity is only rejected for three of the 129 variables at a five per cent level of significance. Table 4.3 contains the results.

Table 4.3 Weak exogeneity test statistics for large GVAR

Country	*F-test*	y^*	π^*	ep^*	ρ^{S*}	ρ^{L*}	p^{oil}
Argentina	F(1,84)	0.18	0.19		0.00	0.43	0.14
Australia	F(2,77)	0.05	1.57		0.86	0.35	0.15
Brazil	F(1,80)	0.44	0.62		0.17	0.00	0.78
Canada	F(1,83)	0.73	0.02		2.57	0.07	0.02
Chile	F(2,79)	1.62	0.13		0.18	0.35	1.46
China	F(1,84)	0.11	0.41		0.80	6.03†	0.86
Euro area	F(1,78)	0.67	0.26		1.04	0.27	0.10
India	F(1,80)	0.28	0.29		0.10	0.46	0.32
Indonesia	F(1,80)	0.10	1.28		0.01	2.52	0.28
Japan	F(1,78)	1.54	0.19		0.60	2.41	3.25
Korea	F(1,78)	5.62†	0.76		0.95	0.03	0.87
Malaysia	F(1,84)	0.78	0.20		0.40	0.67	0.00
Mexico	F(2,83)	3.12†	0.79		0.35	1.14	0.08

New Zealand	F(1,78)	1.69	0.05		0.12	0.17	3.53
Norway	F(2,82)	0.84	1.60		0.46	0.51	2.32
Peru	F(1,80)	1.87	2.14		0.85	0.12	2.10
Philippines	F(1,80)	0.82	0.60		0.00	0.13	3.37
Saudi Arabia	F(1,82)	0.01	0.02		0.75	0.04	0.01
Singapore	F(1,84)	0.40	3.25		0.03	0.29	0.03
South Africa	F(1,78)	0.13	0.21		0.44	0.57	0.04
Sweden	F(2,82)	0.53	0.93		0.55	0.05	0.80
Switzerland	F(2,77)	0.61	0.31		0.02	0.11	0.41
Thailand	F(1,80)	1.77	0.45		0.01	1.41	0.25
Turkey	F(1,80)	0.19	0.88		0.21	0.69	0.13
United Kingdom	F(1,78)	3.03	2.47		0.42	0.19	1.98
United States	F(1,80)	0.14	0.17	0.45	2.41		

† Null hypothesis of weak exogeneity rejected at the 5% level of statistical significance.

Table 4.4 provides the final model specification for the large GVAR, with the domestic lag order (p_i), the foreign lag order (q_i) and the rank for each of the individual VARX* models.

The country-specific VECX* models of the large GVAR are estimated with an unrestricted intercept and a trend restricted to lie in the cointegrating space, whereafter the large GVAR is solved for recursive one-step to eight-steps ahead forecasts from 2005Q1 to 2009Q4.

Table 4.4 Final country-specific VARX* specifications for large GVAR

Country	p_i	q_i	Rank	Country	p_i	q_i	Rank
Argentina	1	1	1	New Zealand	2	1	1
Australia	2	1	2	Norway	1	1	2
Brazil	2	1	1	Peru	2	1	1
Canada	1	1	1	Philippines	2	1	1
Chile	2	1	2	Saudi Arabia	2	1	1
China	1	1	1	Singapore	1	1	1
Euro area	2	1	1	South Africa	2	1	1
India	2	1	1	Sweden	1	1	2
Indonesia	2	1	1	Switzerland	2	1	2
Japan	2	1	1	Thailand	2	1	1
Korea	2	1	1	Turkey	2	1	1
Malaysia	1	1	1	United Kingdom	2	1	1
Mexico	1	1	2	United States	2	1	1

For the initial specification of the VARX* model for the countries in the small GVAR, the AIC is used to determine the number of lags for the domestic (p_i) and foreign (q_i) variables for the country-specific VARX* models, starting with maximum lag orders of two. China has a VARX*(1,1) specification according to the AIC, while the Euro area, South Africa and the US have VARX*(2,1) specifications. To reduce serial correlation in the VARX* for China, its specification is adjusted to VARX*(2,1).

Table 4.5 Trace statistics at different rank orders for cointegration testing for small GVAR

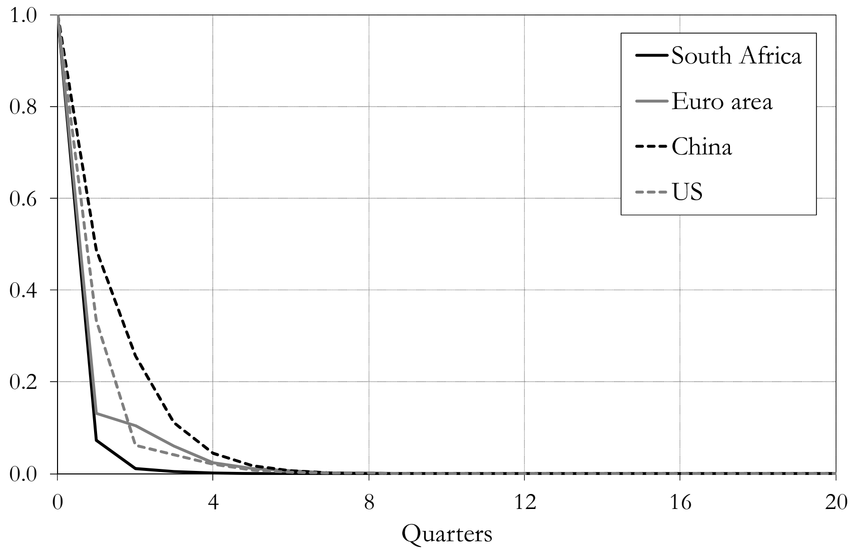
Statistic	*China*	*Euro area*	*South Africa*	*United States*
# Domestic	4	5	5	5
# Foreign	5	5	5	5
$r = 0$	129.76†	**134.95**	169.18†	224.63†
$r = 1$	**76.59**	84.06	**108.49**	130.39†
$r = 2$	34.95	52.63	55.94	85.72†
$r = 3$	13.46	28.52	28.11	**47.85**
$r = 4$		10.29	5.50	20.20

† Null hypothesis (rank = r) rejected at the 5% level of statistical significance.

Based on the trace statistic results in Table 4.5 (where the values in bold font indicate the rank initially chosen for each country), the model for the Euro area has no cointegrating vectors, the models for China and South Africa have one cointegrating vector each, and the model for the US has three cointegrating vectors.

When increasing the rank for the Euro model from zero to one, the PP of the imposed cointegrating vector of the Euro area converges fast. This indicates that the Euro area model does indeed have one cointegrating vector. Since the PP of the US shows non-convergent behaviour with a rank higher than one, the rank is reduced from three to one to avoid misspecification. Figure 4.2 plots the PPs of the cointegrating vectors of South Africa and its three main trading partners (the Euro area, China and the US) for the final specification of the small GVAR.

Figure 4.2 Persistence profiles of the cointegrating vectors in the small GVAR



Weak exogeneity tests are performed on the foreign and global variables that are assumed to be weakly exogenous in the small GVAR. The results in Table 4.6 show that the assumption of weak exogeneity holds for all the relevant variables.

Table 4.6 Weak exogeneity test statistics for small GVAR

Country	*F-test*	y^*	π^*	ep^*	ρ^{S*}	ρ^{L*}	p^{oil}
China	F(1,80)	0.39	0.24		0.52	0.65	0.23
Euro area	F(1,78)	0.01	0.36		1.86	0.32	0.11
South Africa	F(1,78)	0.49	1.23		0.19	0.54	0.01
United States	F(1,80)	0.73	1.09	1.55	0.01		

† Null hypothesis of weak exogeneity rejected at the 5% level of statistical significance.

The final model specification of the small GVAR is summarised in Table 4.7, with the domestic lag order (p_i), the foreign lag order (q_i) and the rank for each of the country-specific VARX* models.

Table 4.7 Final country-specific VARX* specifications for small GVAR

Country	p_i	q_i	**Rank**
China	2	1	1
Euro area	2	1	1
South Africa	2	1	1
United States	2	1	1

The country-specific VECX* models in the small GVAR are estimated with an unrestricted intercept and a trend that is restricted to lie within the cointegrating space. The small GVAR is then solved recursively to get one-step to eight-steps ahead forecasts from 2005Q1 to 2009Q4.

4.4.2 VECX* model

The VECX* model incorporates quarterly domestic and time-varying trade-weighted foreign data for South Africa from 1979Q2 to 2004Q4. As with the GVAR models, recursive out-of-sample forecasts up to eight quarters ahead are compared with the actual data from 2005Q1 to 2009Q4.

For consistency, the same variables used for the GVARs are used for the South African VECX* (see Table 4.1). The same specification is also used, with one lag for the domestic variables, one lag for the weakly exogenous foreign variables and a rank of one.

The marginal models of the weakly exogenous foreign variables of the VECX* are used to forecast out-of-sample values for the foreign variables. The marginal models are all VAR(1), that is VAR models of order one, with an intercept. Thus, the marginal models for the weakly exogenous foreign variables each include one lag for the differenced endogenous variables, one lag for the differenced exogenous variables and an intercept. More lags cannot be included due to data constraints. The forecasts for the domestic variables are computed based on the forecasted exogenous variables.

The marginal models for the weakly exogenous foreign variables each include one lag for the differenced endogenous variables, one lag for the differenced exogenous variables and an intercept.

4.4.3 Univariate AR and RW models

Univariate AR and RW models are estimated for real GDP and inflation respectively from 1979Q2 to 2004Q4. Recursive out-of sample forecasts are then determined from 2005Q1 to 2009Q4, each time for a forecast horizon (h) up to eight quarters. These simple models are often used in the literature as benchmark models as their forecasts are 'surprisingly hard to beat' (Pesaran *et al.*, 2009a; Smith, 2013a).

An AR(1) model specification, thus an AR model with a lag order of one, without a trend proves best for both the real GDP and inflation from 1979Q2 to 2004Q4. The AR(1) specifications for real GDP (y_t) and inflation (π_t) are

$y_t = \alpha_y + \beta_y y_{t-1} + \varepsilon_{y1,t}$ and $\pi_t = \alpha_\pi + \beta_\pi \pi_{t-1} + \varepsilon_{\pi 1,t}$,

while the forecast equations for real GDP ($y_{t+h/t}$) and inflation ($\pi_{t+h/t}$) are

$y_{t+h/t} = \hat{\alpha}_y + \hat{\beta}_y y_{t+h-1/t}$ and $\pi_{t+h/t} = \hat{\alpha}_\pi + \hat{\beta}_\pi \pi_{t+h-1/t}$.

For the sample period from 1979Q2 to 2004Q4, a RW with a drift fits the real GDP series the best. A RW without a drift fits the inflation series well. The RW model specifications for real GDP and inflation respectively are

$y_t = \mu_y + y_{t-1} + \varepsilon_{y2,t}$ and $\pi_t = \pi_{t-1} + \varepsilon_{\pi 2,t}$,

while the forecast equations for real GDP and inflation are

$y_{t+h/t} = h\hat{\mu}_y + y_t$ (where $\hat{\mu}_y$ is estimated using $\Delta y_t = \mu_y + \varepsilon_{y2,t}$) and $\pi_{t+h/t} = \pi_t$.

4.5. FORECAST EVALUATION

The RMSFEs of all the models are compared to determine which model provides the best forecasts of two key South African variables: GDP and inflation[8]. The RMSFEs for one-quarter ahead up to eight-quarters ahead are calculated for the recursive out-of-sample forecasts from 2005Q1 to 2009Q4. Section C.1 in Appendix C shows the formula used to calculate the RMSFEs.

Figure 4.3 compares the RMSFEs for South African GDP at different forecast horizons for the three models. The forecasts of the large GVAR are consistently more accurate than that of the small GVAR. Although the VECX* seems to outperform the large GVAR model in the first four quarters, the large GVAR provides better forecasts in the subsequent four quarters (five to eight quarters ahead). The forecasts of both the small and large GVARs are better than that of the VECX* in the last three quarters. Both GVARs and the VECX* outperform the basic benchmark models, an AR(1) model and a RW model, over all forecast horizons.

[8] If the fixed trade-weighted approach is used instead of the time-varying trade-weighted approach, the forecast rankings of the models in the study are different. This is unsurprising – if the substantial change in trade weights, especially towards the end of the sample, is ignored, the results could be misleading.

Figure 4.3 RMSFEs for South African GDP

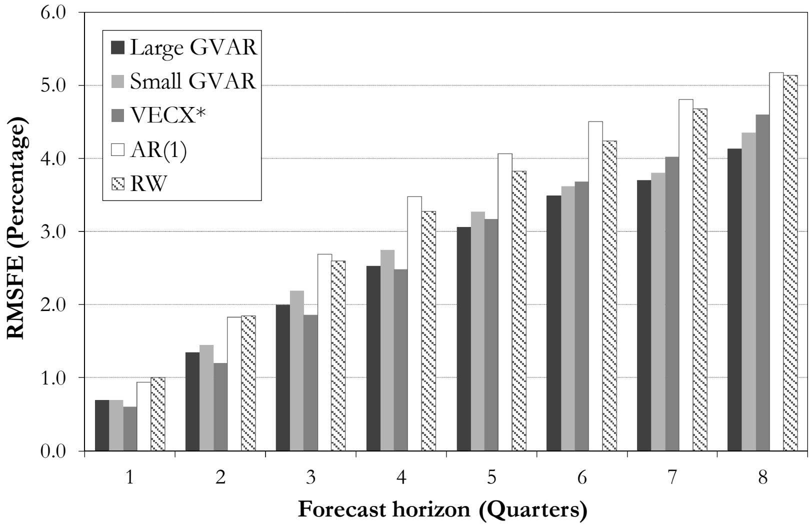
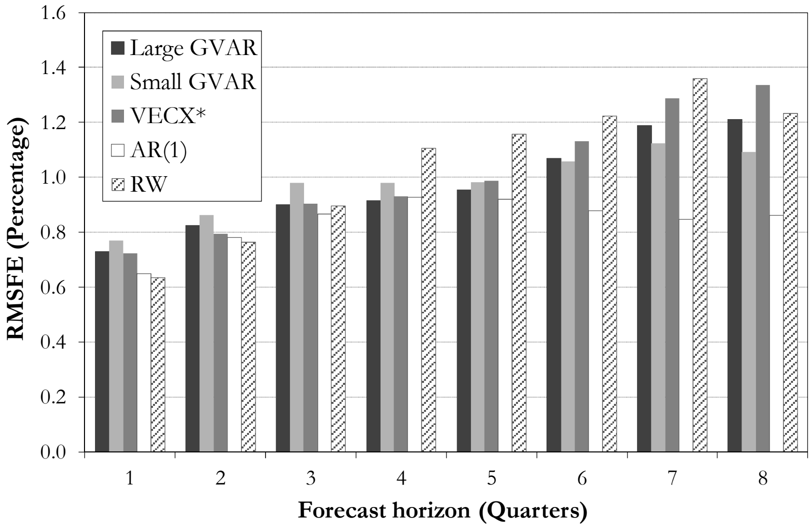


Figure 4.4 compares the RMSFEs for South African inflation. The forecasts of the large GVAR are more accurate than the forecasts of the small GVAR up to a five-quarter horizon. Thereafter, the small GVAR forecasts appear better than that of the large GVAR. The VECX* provide marginally better forecasts than the GVAR models in the first two quarters, but thereafter the VECX* is outperformed by first the large GVAR and then both the GVARs. For forecasts up to three quarters ahead, the benchmark AR(1) and RW models produce more accurate forecasts than the GVAR models and the VECX*. Thereafter, all the other models outperform the RW model, except at an eight-quarter forecast horizon, where the RW model is better than the VECX*. From a forecast horizon of five quarters or more, the AR(1) model produces the best forecasts. The good forecast performance of the AR(1) is in line with expectations, due to inflation being highly autoregressive in nature. If inflation is the only series to forecast, an AR(1) model would be better, but if the aim is to forecast additional key macroeconomic variables while accounting for relationships and feedback effects between macroeconomic variables, as in this study, a GVAR or VECX* model will be more suitable.

Figure 4.4 RMSFEs for South African inflation



The forecast sample sizes in this study are small, ranging between 13 (for eight-quarter ahead forecasts) and 20 (for one-quarter ahead forecasts). To evaluate whether the differences in the GDP and inflation forecasts are significant, the modified Diebold-Mariano test (Harvey, Leybourne & Newbold, 1997) is considered, since it has better size properties than the original Diebold-Mariano (1995) test for small samples and for forecast horizons greater than one period, even when serial correlation is present. The null hypothesis is that the forecast errors are not significantly different. Section C.2 in Appendix C provides more information about the test. Although the modified Diebold-Mariano test is applicable for non-nested models, while several models in this study are nested, the results of the modified Diebold-Mariano test are reported for all the models (nested and non-nested). An appropriate test for nested models is the Giacomini and White (2006) test, but it requires rolling forecasts and not recursive forecasts. The forecasts in this study are recursive forecasts. In line with Assenmacher-Wesche and Geissmann (2013), the Giacomini-White test is therefore not performed.

Table 4.8 and Table 4.9 show the results of the modified Diebold-Mariano test for the evaluation of GDP and inflation forecasts respectively. The tables include the test statistics of the 10 possible forecast comparisons. These are the large GVAR versus the small GVAR, VECX*, AR(1) and RW models (thus, the large GVAR compared to each of the other models); the small GVAR versus the VECX*, AR(1) and RW models; the VECX* versus the AR(1) and RW models; and the AR(1) models versus the RW models. For each comparison, negative test statistics indicate that the forecasts of the first model in the comparison are better, while positive test statistics indicate that the forecasts of the second model are better. For example, when the large GVAR is compared to the small GVAR, negative values show that the large GVAR forecasts outperform the small GVAR forecasts and positive values show that the small GVAR forecasts outperform the large GVAR forecasts.

The modified Diebold-Mariano test statistics are compared to critical values of the Student's *t*-distribution at a 10 per cent level of significance. The asterisks in the tables denote statistically significant test statistics. Most of the test statistics are insignificant, thereby indicating that the forecast differences are not statistically significant. Since the modified Diebold-Mariano test is not applicable to nested models, the results may be misleading. Expanding the out-of-sample period may show that more of the forecast differences are statistically significant, but it would be at the cost of specifying models that use less information on the substantial changes in trade weights.

Table 4.8 Modified Diebold-Mariano test statistics for GDP forecasts

Forecast horizon	Large GVAR vs. small GVAR	Large GVAR vs. VECX*	Large GVAR vs. AR(1)	Large GVAR vs. RW	Small GVAR vs. VECX*
1	0.011	0.887	-1.526	-2.974*	1.743*
2	-1.917*	0.762	-1.077	-2.855*	1.518
3	-3.974*	0.502	-1.004	-1.959*	1.177
4	-1.933*	0.125	-0.850	-1.312	0.952
5	-0.595	-0.253	-0.719	-0.746	0.956
6	-0.156	-0.255	-0.611	-0.455	-0.592
7	-0.063	-0.256	-0.500	-0.422	-0.795
8	-0.095	-0.240	-0.380	-0.277	-2.113*
Forecast horizon	**Small GVAR vs. AR(1)**	**Small GVAR vs. RW**	**VECX* vs. AR(1)**	**VECX* vs. RW**	**AR(1) vs. RW**
1	-1.207	-2.274*	-1.385	-2.497*	-0.492
2	-0.823	-1.817*	-0.994	-2.360*	-0.051
3	-0.778	-1.346	-0.887	-2.967*	0.113
4	-0.638	-1.169	-0.698	-2.076*	0.146
5	-0.485	-0.825	-0.514	-1.050	0.113
6	-0.373	-0.744	-0.359	-0.604	0.089
7	-0.277	-1.211	-0.241	-0.600	0.031
8	-0.170	-0.596	-0.130	-0.333	0.006

According to the results in Table 4.8, the GDP forecasts of the large GVAR are significantly better than that of the small GVAR for a forecast horizon between two and four quarters. This confirms earlier conclusions from the graphical evidence that the forecast performance of the large GVAR is generally better for forecasting GDP. This is in line with expectations, since the large GVAR incorporates a much larger proportion of the trading partners of South Africa. Although the VECX* model forecast is significantly better than that of the small GVAR at a one-quarter horizon, the small GVAR forecasts are better from a five-quarter forecast horizon onwards. At an eight-quarter horizon, the small GVAR forecast of GDP is significantly better than the VECX* forecast. The GDP forecasts of the GVARs and the VECX* are significantly more accurate than that of the RW model at shorter forecast horizons.

Despite the large forecast differences evident in Figure 4.4, the modified Diebold-Mariano test statistics in Table 4.9 indicates only four forecasts that are significantly different in the comparison of inflation forecasts.

Table 4.9 Modified Diebold-Mariano test statistics for inflation forecasts

Forecast horizon	Large GVAR vs. small GVAR	Large GVAR vs. VECX*	Large GVAR vs. AR(1)	Large GVAR vs. RW	Small GVAR vs. VECX*
1	-0.795	0.286	0.602	0.564	0.819
2	-0.597	1.419	0.302	0.513	1.064
3	-0.776	-0.113	0.211	0.022	0.838
4	-0.481	-0.209	-0.094	-0.860	0.356
5	-0.180	-0.293	0.377	-0.708	-0.015
6	0.069	-0.413	2.467*	-0.444	-0.231
7	0.498	-0.544	0.691	-0.387	-0.444
8	2.126*	-0.613	0.829	-0.085	-0.663
Forecast horizon	**Small GVAR vs. AR(1)**	**Small GVAR vs. RW**	**VECX* vs. AR(1)**	**VECX* vs. RW**	**AR(1) vs. RW**
1	1.056	1.026	0.509	0.498	0.160
2	0.515	1.072	0.091	0.298	0.119
3	0.492	0.659	0.188	0.045	-0.127
4	0.244	-2.570*	0.017	-0.797	-0.613
5	0.344	-1.387	0.335	-0.537	-0.757
6	0.921	-0.920	1.004	-0.198	-2.250*
7	1.504	-0.752	0.643	-0.098	-0.722
8	0.945	-0.718	0.744	0.150	-0.435

The small GVAR forecast of inflation is significantly better than that of the large GVAR at a forecast horizon of eight quarters, while the AR(1) forecast significantly outperforms that of the large GVAR at a six-quarter horizon. The RW forecasts are significantly less accurate than the small GVAR forecast at a four-quarter horizon and the AR(1) model at a six-quarter horizon.

As mentioned earlier, the results of the modified Diebold-Mariano test may be misleading for several of the model comparisons, since the test is not valid for nested models. Therefore, more emphasis is placed on the comparison of the raw RMSFEs of the different models (see Figure 4.3 and Figure 4.4, with the accompanying discussions at the start of Section 4.5).

4.6. CONCLUSION

The forecast errors of the GVAR models are lower than that of the country-specific VECX* for South Africa at longer forecast horizons (more than four quarters ahead), but the differences are not statistically significant. It would therefore be sufficient to develop a simple VECX* for South Africa if the aim is to forecast only domestic variables at short forecast horizons. However, if one is interested in global trade linkages and forecasts of variables for specific foreign countries or areas, a VECX* for South Africa would not suffice. Then, a GVAR model that includes many countries and global trade linkages would be more relevant and at least as good, if not better, as a VECX* for forecasting domestic variables.

A large (33-country) GVAR generally provides more accurate forecasts of key domestic variables than a customised small (11-country) GVAR for South Africa. This is contrary to one of the findings in Di Mauro and Pesaran (2013) that modelling only a few countries in a GVAR for a small, open economy provides reliable forecasts. This is not the case for South Africa – although it is a small open economy – since modelling only a few countries in a customised GVAR for South Africa represents a much smaller percentage of trade with the rest of the world than in the case of a small GVAR for Switzerland (Assenmacher, 2013). The majority of Switzerland's trade is with a few countries, while South African trade is more diverse. The trade shares of the main trading partners of Switzerland have been relatively stable, while the trade shares of South Africa's trading partners have changed markedly since the mid-1990s. By using time-varying trade weights in the model to account for this, it is important to consider all the countries involved in these changes, thereby favouring a large model.

The research in this chapter confirms that the GVAR approach is suitable for forecasting and it stresses the importance of incorporating sufficient information on international trade linkages in macroeconomic modelling.

The next chapter summarises the findings of this study and contains a discussion of additional avenues of research, which include 'pooling' methods, such as forecasts averaged over different model specifications and different samples, to improve the GVAR forecasts of domestic variables for South Africa.

CHAPTER 5

GENERAL CONCLUSION AND AREAS OF FUTURE RESEARCH

5.1. INTRODUCTION

In this concluding chapter, Section 5.2 highlights the contributions of the thesis and Section 5.3 summarises the main findings of the study. The final section, Section 5.4, contains avenues for future research.

5.2. CONTRIBUTIONS OF THIS STUDY

The first contribution of this thesis is the development of a VECX* model for South Africa, with time-varying trade-weighted foreign variables to incorporate the large changes in the trade shares of the country's key trading partners (refer to Chapter 2). This study applies the VECX* model to confirm that the transmission of monetary policy to inflation is in line with expectations.

The second and main contribution of this thesis is to investigate how the transmission of output shocks to China and the US respectively on South Africa have changed between 1995 and 2009. Given the large change in trade patterns over the same period, the significant change in effects (refer to Chapter 3) is in line with expectations. For this analysis, the study uses a GVAR model with time-varying weighs. The country-specific foreign variables for each of the 33 countries in the model are compiled with time-varying trade-weighted data to account for the change in global trade linkages.

The final contribution of this thesis is to compare the forecast errors of five different models (refer to Chapter 4). These models are a large (33-country) GVAR, a customised small GVAR for South Africa, a South African VECX*, AR processes and RW processes. The study shows that a large GVAR model generally provides better forecasts of GDP and inflation for South Africa than a small GVAR. The forecasts of both the GVARs outperform the forecasts of the VECX* for South Africa over forecast horizons longer than four quarters. This study illustrates that the vast country and global trade linkage information, incorporated in a GVAR, helps to explain the movements in domestic variables.

5.3. SUMMARY OF KEY FINDINGS

Chapter 2 contains the findings of the VECX* model for South Africa. Three significant long-run relations, in line with the number of cointegrating vectors in the VECX*, are identified for the country. These are the augmented purchasing power parity (PPP^A), the uncovered interest parity (UIP) and the modified Fisher parity (LIR or long-run interest rate rule). The three long-run relationships are imposed on the VECX*, before examining the effect of a monetary policy shock (an increase in the repo rate) on output and inflation. It indicates the correct functioning of the overall monetary transmission mechanism in South Africa. After an increase in the repo rate, it takes around 12 months before the full negative impact on output is observed, while it takes around 24 months before the full negative impact on inflation is observed.

Chapter 3 suggests reasons why the recent global crisis did not impact South Africa economy as much as it influenced developed economies. Due to China's emergence in the world economy, the risk of the effect of slower economic growth in China for South Africa and the rest of the world has increased considerably. China became the largest trading partner (on a country level) of South Africa in 2009. Before 1993, South Africa did not trade with China. Therefore, comparing the long-term impact of a one per cent shock to Chinese GDP on South African GDP in 2009 and in 1995 respectively, the effect is much larger in 2009 than in 1995. The US used to be South Africa's largest trading partner in the early 1980s; however, it is now only the third most important trading partner of the country. As a result, the long-term impact of a one per cent US GDP shock on South African GDP only has a quarter of the effect in 2005 compared to a similar shock in 1995. The impact of a similar shock to US GDP on South African GAP is insignificant by 2009.

The results of Chapter 4 show that the forecasts of a small GVAR (including 11 countries) are less precise than those of a large GVAR model (incorporating 33 countries), suggesting that sufficient international trade linkages should be taken into account when forecasting. The forecasts of the small and large GVARs are mostly more accurate than the VECX* forecasts, especially at longer forecast horizons. In addition, the GVAR forecasts are more precise than those of the standard benchmark models (AR and RW), except for inflation, where the best forecasts are those of an AR(1) model due to the autoregressive nature of inflation. The findings imply that the additional information contained in GVAR models, especially the global trade linkages that allows for linkages between international and domestic variables, improves the forecasts of domestic variables in South Africa.

5.4. AREAS OF FUTURE RESEARCH

This study reveals many areas for further research.

The first future research opportunity is to determine whether and how global economic shocks affect the transmission of monetary policy in South Africa. This is related to the research in Chapter 2. Bain and Howells (2003) mention that many factors influence the time lags involved in the monetary transmission mechanism, including 'the state of business and consumer confidence, how this confidence is influenced by monetary policy changes, events in the world economy and expectations about future inflation'. If global economic shocks do have an effect on the domestic monetary transmission mechanism, then policy makers would need to consider this in the aftermath of international crises. For such a study, one could either consider a general global shock in a VECX* model for South Africa or a shock to a specific country in a GVAR model that contains South Africa.

The GVAR models in this study incorporate changes in global trade linkages. However, ideally, the models should also account for changes in global financial linkages. Due to a lack of data on financial linkages over the full sample period between the countries included in this study, this was not possible. It would be worthwhile to investigate the development of a smaller GVAR over a shorter sample that incorporates data for both global trade and financial linkages, to determine if and how the incorporation of global financial linkages affects the transmission of shocks in the rest of the world to the South African economy.

To determine the effect of structural shocks in the rest of the world on South Africa, the use of a GVAR model combined with a structural DSGE model would be valuable. Dées *et al.* (2010) developed such a Multi-Country New Keynesian (MCNK) model. With the MCNK model, it is possible to analyse the transmission of different structural shocks (that is, supply, demand and monetary policy shocks) in specific foreign countries to the South African economy. Such analysis would be beneficial for policy makers.

In the literature, the use of 'pooling' techniques improves GVAR forecasts (Assenmacher-Wesche & Geissmann, 2013; Pesaran *et al.* 2009a; Smith, 2013a). Therefore, it could be useful to extend the forecasting research, to determine whether double-averaged GVAR forecasts, over different GVAR specifications and over different sample periods, are significantly better than that of individual GVAR models and benchmark models. A comparison of the forecasts of more variables, including variables for the main trading partners of South Africa, would also be valuable.

Finally, although the large GVAR with 33 countries outperforms the small GVAR with 11 countries, it could be helpful to determine whether there is a medium-sized GVAR for South Africa, which is not outperformed by a large GVAR. A medium-sized model could be simpler to maintain over the long run.

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APPENDIX A

Appendix to Chapter 2

A.1 DATA DEFINITIONS AND SOURCES

Table A.1 provides full definitions, calculations and data sources for the variables in Table 2.1. This is followed by an explanation of the calculations of all series involving foreign data.

Table A.1 Variable definitions, calculations and data sources

Variable	Definition	Calculation	Data source
y	Real GDP of South Africa (Index: 2000 = 100)	*ln*(real GDP)	Real GDP: IFS 99BVRZF‡
π	Inflation rate of South Africa (Quarterly %)	Δ(*ln*(CPI))	Calculated
r	Repo rate of South Africa (Quarterly %)	0.25**ln*(1+repo rate/100)	Repo rate: IFS 60ZF
e	Nominal effective exchange rate of South Africa (Time-varying trade-weighted Rand per foreign currency)	*ln*(nominal effective exchange rate) [Nominal effective exchange rate = time-varying trade-weighted exchange rate of South Africa]	Bilateral exchange rates (units of foreign currency per US Dollar): Bloomberg‡
p	CPI of South Africa (Index: 2000 = 100)	*ln*(CPI)	CPI: IFS 64ZF‡ (Seasonally adjust the series)
ep	Real effective exchange rate of South Africa	*ln*(real effective exchange rate) $= e - p$	Calculated
lr	Long-term interest rate of South Africa (Quarterly %)	0.25**ln*(1+long-term interest rate/100)	Long-term interest rate (government bond yield): IFS 61ZF‡
$m3$	Real M3 of South Africa (Constant 2000 prices)	*ln*(real M3) [nominal M3 = real M3/CPI *100]	Nominal M3: IFS 59MCZF
y^*	Time-varying trade-weighted foreign real GDP (Index: 2000 = 100)	*ln*(foreign real GDP)	Real GDP for each of the 32 other countries: Source depends on country‡
p^*	Time-varying trade-weighted foreign CPI (Index: 2000 = 100)	*ln*(foreign CPI)	CPI for each of the 32 other countries: Source depends on country‡
r^*	Time-varying trade-weighted foreign short-term interest rate (Quarterly %)	0.25**ln*(1+foreign short-term interest rate/100))	Short-term interest rate for each of the 32 countries: Source depends on country‡
p^{oil}	Oil price (US Dollar)	*ln*(oil price)	Oil price (Brent): Bloomberg Ticker: CO1 Comdty‡
$y - y^*$	Ratio of South African real GDP to time-varying trade-weighted foreign real GDP	Ratio of real GDP) to foreign real GDP $= y - y^*$	Calculated
$p - p^*$	Ratio of South African CPI to time-varying trade-weighted foreign CPI	Ratio of CPI to foreign CPI $= p - p^*$	Calculated
$d92$	Dummy variable to represent the structural change in South Africa in the early 1990s	Dummy variable: 1 from 1992Q1 onwards	Created

‡ The data are from the GVAR Toolbox 1.1 dataset (Smith & Galesi, 2011), known as the '2009 vintage'.

It is worthwhile to note that the real effective exchange rate is calculated as $(e - p)$, consistent with the GVAR literature and differs from the usual definition of $(e - p + p^*)$. The nominal effective exchange rate is calculated as the time-varying trade-weighted foreign exchange rate of South Africa. Since the dataset contains the bilateral exchange rates of the countries in units of foreign currency per US Dollar, the bilateral exchange rates with South Africa in units of Rand per foreign currency are obtained by dividing the South African Rand per US Dollar by each of the foreign currencies per US Dollar. To create a weighted, effective exchange rate for South Africa, these bilateral exchanges rates are weighted with the three-year moving average trade shares of South Africa with the corresponding country.

Thus, the calculation of the nominal Rand effective exchange rate is

$$nominal\ effective\ exchange\ rate_t = \prod_{j=1}^{32} \left[\frac{sar_t}{er_t} \right]^{w_{jt}},$$

where $j = 1, 2, \ldots, 32$ refers to the trading partners of South Africa, sar_t is the South African Rand exchange rate in terms of the US Dollar, er_t is the exchange rate of country j in terms of the US Dollar and w_{jt} is the trade share of country j in the trade (average of exports and imports) with South Africa at time t.

Foreign real output (y^*), foreign prices (p^*) and the foreign short-term interest rate (r^*) are calculated by weighting the relevant country-specific data with the three-year moving average trade shares. For example, the formula to calculate foreign real output at time t is

$$y_t^* = \sum_{j=1}^{32} w_{jt} y_{jt},$$

where y_{jt} is the natural logarithm of the real output of country j and w_{jt} is the associated trade weight of country j in trade with South Africa.

A.2 UNIT ROOT TEST RESULTS

The test statistics of the Weighted-Symmetric Augmented Dickey Fuller (WS-ADF) unit root test are included in Table A.2. The AIC determines the lag length of each of the test regressions. The auxiliary regressions of y, ep, lr, y^*, p^*, p^{oil} include a trend and an intercept for the variables in levels and an intercept for the variables in first differences. The auxiliary regressions of π, r and r^* include only an intercept for the variables in both levels and first differences.

Table A.2 WS-ADF test statistics for VECX* variables

	y	π	r	ep	lr	y^*	p^*	r^*	p^{oil}
Levels	-1.67	-2.87*	-2.67*	-3.06	-0.69	-2.04	0.03	-1.32	-1.28
First differences	-5.77*	-8.22*	-6.97*	-4.80*	-8.38*	-3.78*	-3.50*	-6.08*	-6.46*

An asterisk denotes rejection of the null hypothesis of a unit root with a 5% level of significance.

A.3 GIRFS FOR VECX* FOR SOUTH AFRICA

Figure A.1 GIRFs for output with 95% bootstrapped confidence intervals

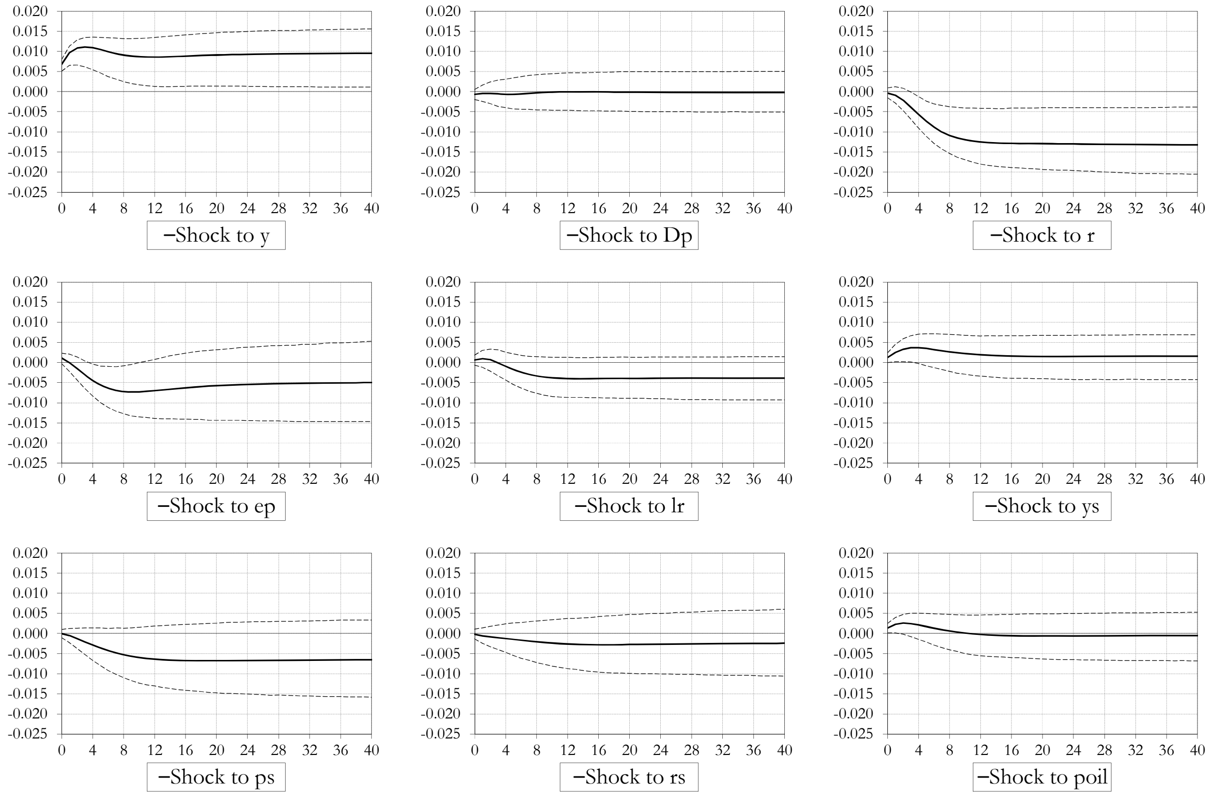


Figure A.2 GIRFs for inflation with 95% bootstrapped confidence intervals

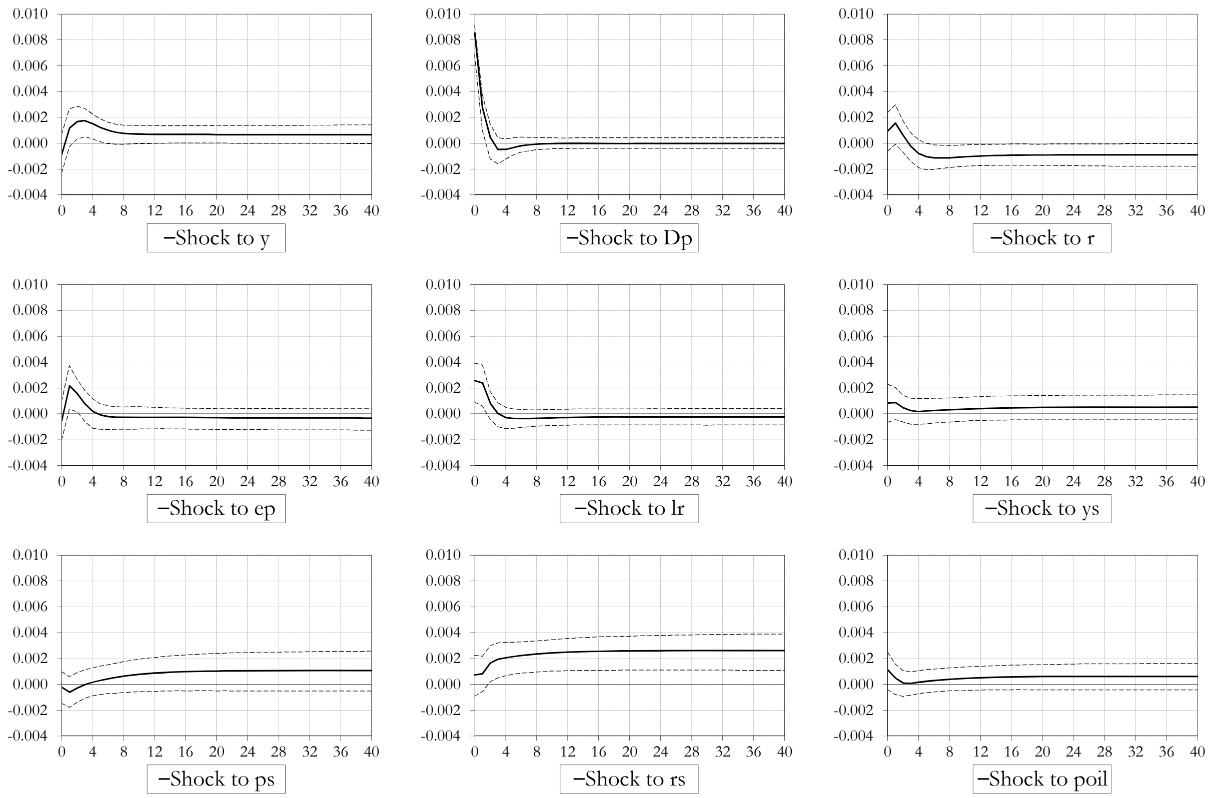


Figure A.3 GIRFs for repo rate with 95% bootstrapped confidence intervals

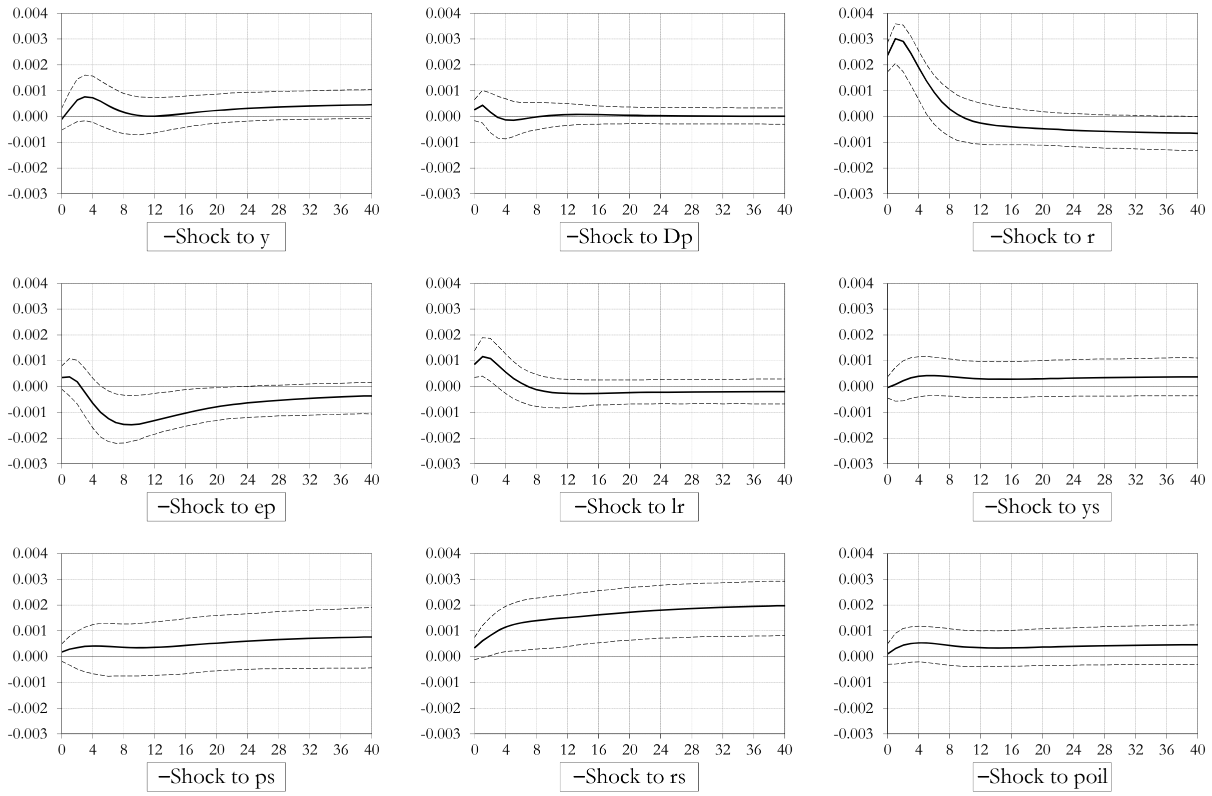


Figure A.4 GIRFs for real effective exchange rate with 95% bootstrapped confidence intervals

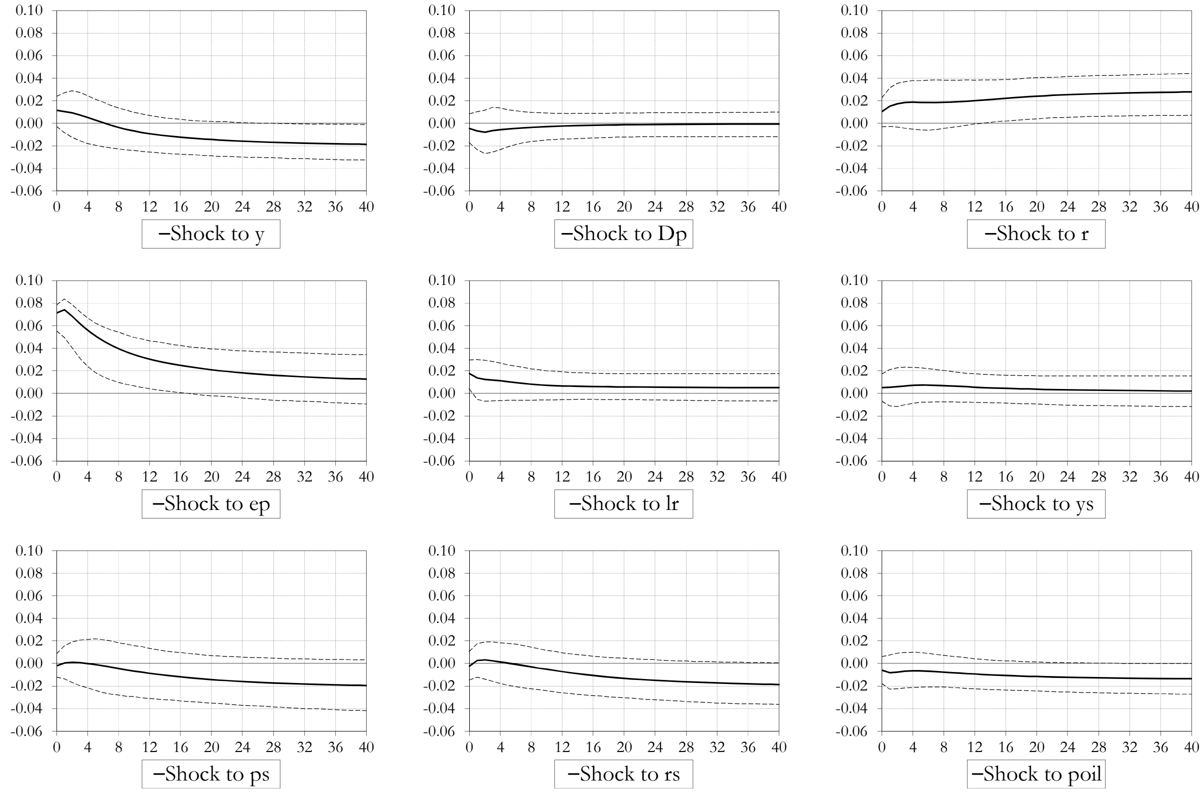


Figure A.5 GIRFs for long-run interest rate with 95% bootstrapped confidence intervals

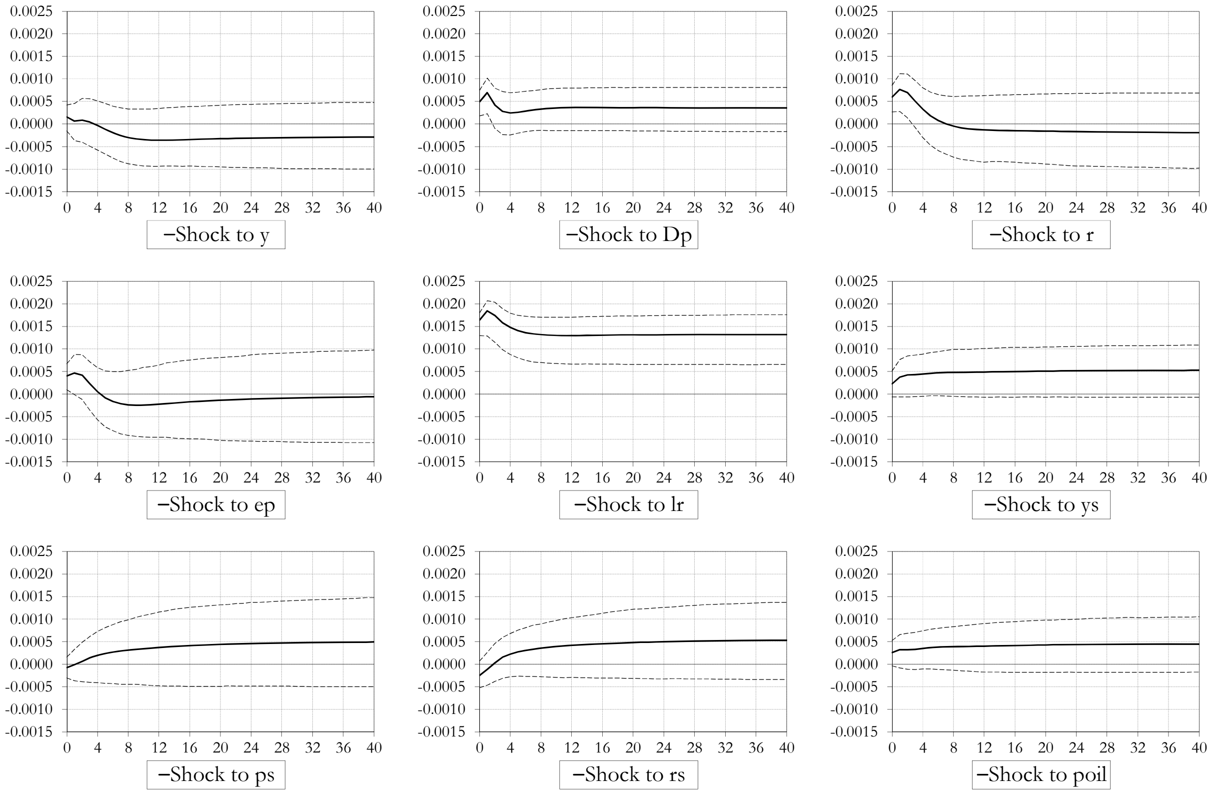


Figure A.6 GIRFs for foreign output with 95% bootstrapped confidence intervals

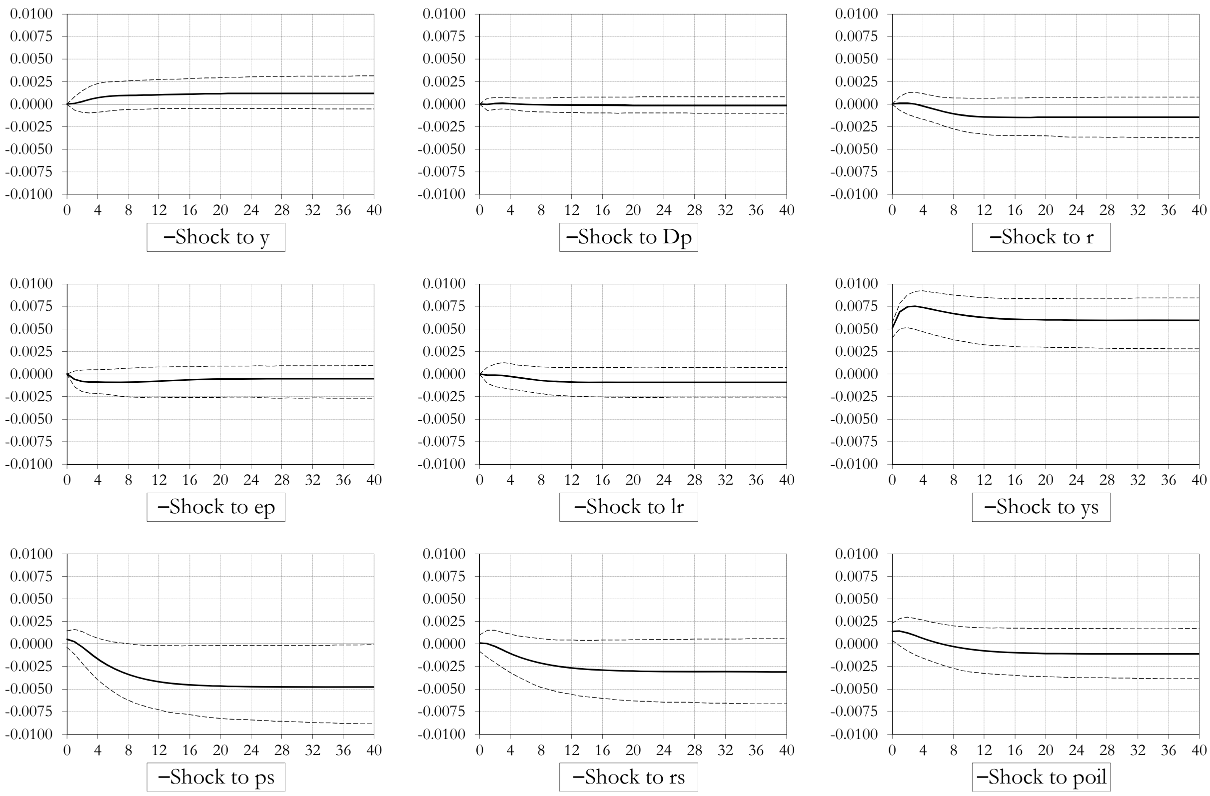


Figure A.7 GIRFs for foreign prices with 95% bootstrapped confidence intervals

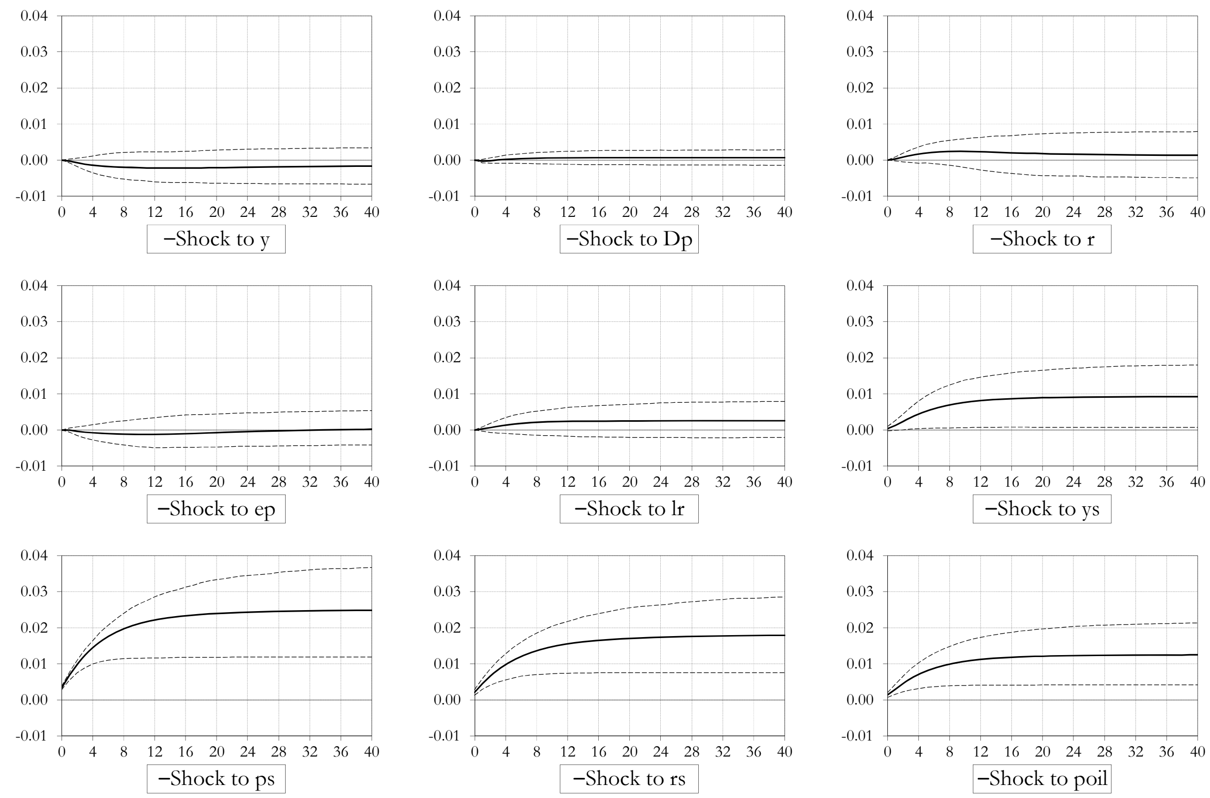


Figure A.8 GIRFs for foreign short-term interest rates with 95% bootstrapped confidence intervals

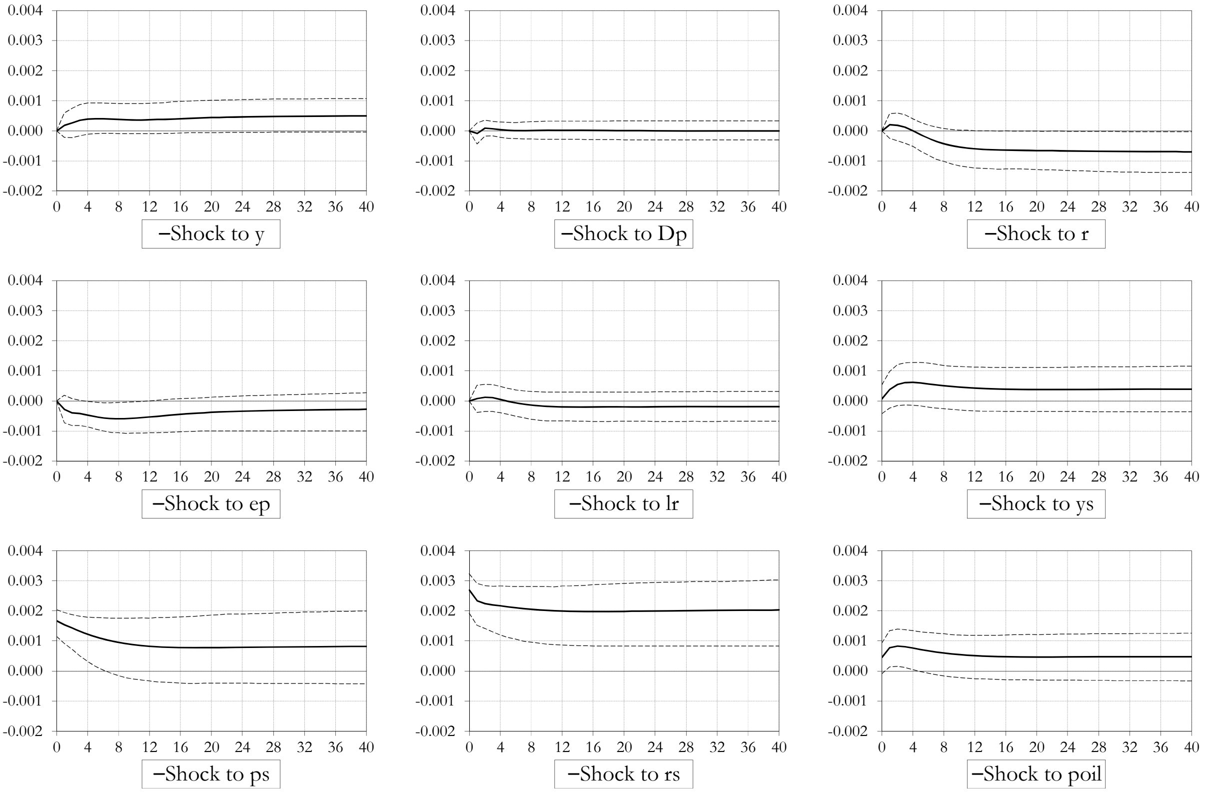
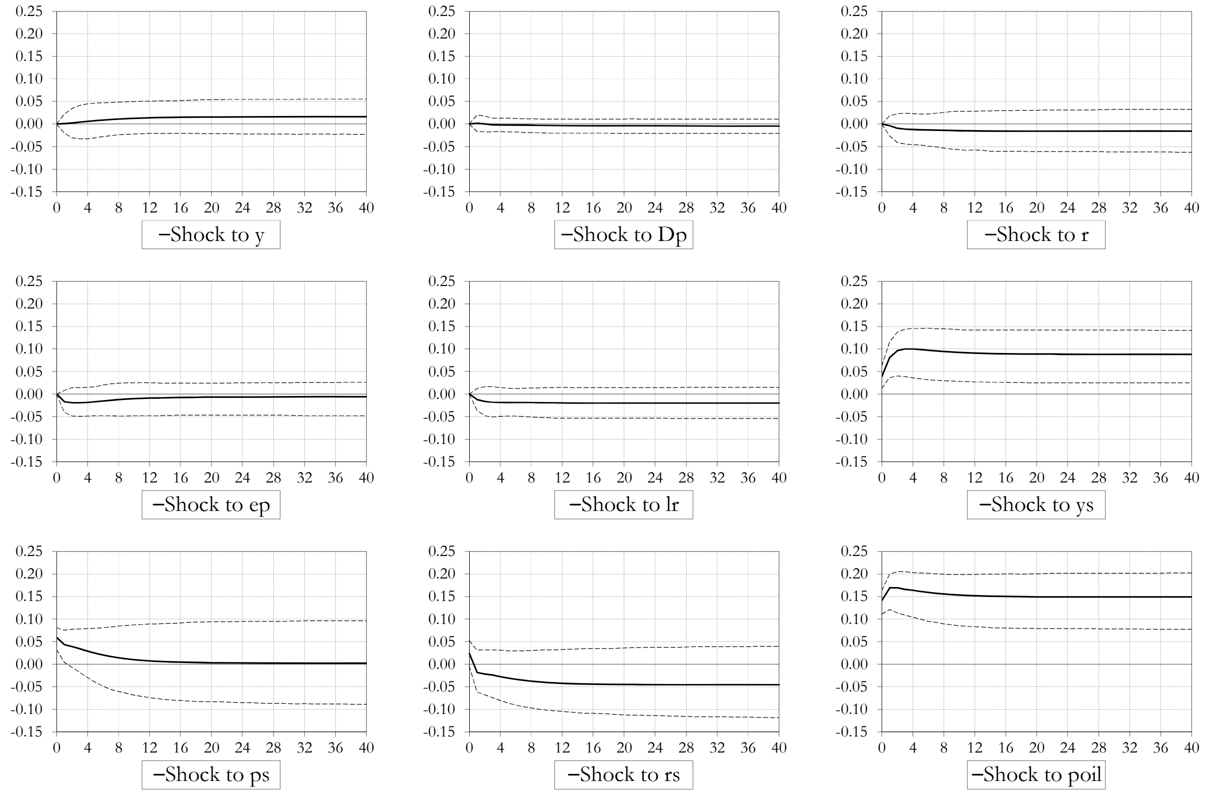


Figure A.9 GIRFs for oil price with 95% bootstrapped confidence intervals



APPENDIX B

Appendix to Chapter 3

B.1 UNIT ROOT TEST RESULTS

Table B.1 WS-ADF test statistics for domestic variables in the GVAR

Variable	*Argentina*	*Australia*	*Brazil*	*Canada*	*Chile*	*China*	*Euro area*
y (with trend)	-2.20	-3.06	-2.39	-2.70	-2.40	-2.04	-1.18
y (no trend)	-0.18	1.83	1.70	0.97	1.05	0.72	0.87
Δy	-5.15*	-6.47*	-6.21*	-4.92*	-6.16*	-3.54*	-3.90*
π (with trend)	-3.70*	-3.67*	-2.71	-3.48*	-5.06*	-3.04	-2.01
π (no trend)	-2.61*	-2.42	-2.45	-1.21	-1.87	-3.02*	-0.68
$\Delta\pi$	-12.36*	-9.80*	-6.30*	-7.61*	-7.05*	-6.85*	-6.66*
q (with trend)	-3.26*	-4.52*	-	-2.86	-2.30	-	-2.45
q (no trend)	-2.77*	-0.74	-	-0.76	-0.33	-	-0.93
Δq	-6.76*	-5.69*	-	-6.21*	-5.08*	-	-6.76*
ep (with trend)	-2.26	-2.62	-2.17	-1.78	-2.33	-1.25	-2.36
ep (no trend)	-2.09	0.29	-1.00	1.14	-1.18	-1.23	-0.16
Δep	-7.24*	-7.88*	-7.25*	-7.46*	-6.91*	-7.08*	-6.83*
ρ^S(with trend)	-2.71	-3.29*	-2.79	-4.08*	-5.00*	-1.63	-3.04
ρ^S (no trend)	-2.27	-1.95	-2.65*	-1.17	-1.04	-1.43	-1.18
$\Delta\rho^S$	-15.88*	-7.47*	-9.18*	-5.86*	-6.76*	-6.13*	-3.91*
ρ^L (with trend)	-	-2.08	-	-3.54*	-	-	-3.05
ρ^L (no trend)	-	-1.22	-	-1.28	-	-	-1.02
$\Delta\rho^L$	-	-5.64*	-	-5.69*	-	-	-5.14*
Variable	*India*	*Indonesia*	*Japan*	*Korea*	*Malaysia*	*Mexico*	*New Zealand*
y (with trend)	-1.22	-1.80	-0.80	-1.10	-2.21	-3.34*	-1.76
y (no trend)	1.33	2.51	0.83	0.84	1.72	0.95	1.41
Δy	-7.92*	-7.01*	-3.94*	-5.24*	-5.45*	-4.09*	-6.53*
π (with trend)	-5.69*	-5.84*	-3.16	-2.86	-5.45*	-3.80*	-3.81*
π (no trend)	-5.39*	-5.85*	-1.53	-2.18	-5.11*	-2.81*	-2.40
$\Delta\pi$	-9.00*	-8.68*	-7.57*	-6.82*	-8.91*	-5.76*	-7.49*
q (with trend)	-3.67*	-	-1.85	-2.74	-3.02	-	-2.38
q (no trend)	-0.87	-	-1.67	-1.64	-1.90	-	-1.69
Δq	-7.22*	-	-5.06*	-5.71*	-6.15*	-	-6.16*
ep (with trend)	-1.22	-2.59	-2.05	-2.82	-2.20	-3.70*	-2.85
ep (no trend)	-0.26	-2.64*	-0.30	-0.94	-0.87	-0.80	-0.39
Δep	-5.65*	-8.10*	-5.24*	-5.60*	-7.25*	-7.12*	-6.55*
ρ^S(with trend)	-3.03	-4.10*	-3.20	-2.59	-2.12	-2.03	-3.12
ρ^S (no trend)	-2.70*	-4.05*	-1.80	-0.88	-1.99	-1.78	-1.95
$\Delta\rho^S$	-6.66*	-6.42*	-4.94*	-7.80*	-6.87*	-6.25*	-8.15*
ρ^L (with trend)	-	-	-2.50	-2.46	-	-	-2.02
ρ^L (no trend)	-	-	-0.85	-0.34	-	-	-0.96
$\Delta\rho^L$	-	-	-5.44*	-6.73*	-	-	-7.58*

Variable	*Norway*	*Peru*	*Philippines*	*Saudi Arabia*	*Singapore*	*South Africa*	*Sweden*
y (with trend)	-1.80	-1.46	-2.18	-0.56	-1.49	-1.54	-2.44
y (no trend)	2.51	0.59	0.46	0.58	1.68	1.26	0.65
Δy	-6.39*	-7.63*	-3.56*	-2.95*	-6.11*	-5.05*	-4.51*
π (with trend)	-4.75*	-3.35*	-5.17*	-4.47*	-3.78*	-4.27*	-3.69*
π (no trend)	-2.03	-3.13*	-4.40*	-3.34*	-3.43*	-2.80*	-2.06
$\Delta\pi$	-7.86*	-7.99*	-6.86*	-8.79*	-9.86*	-8.31*	-6.84*
q (with trend)	-4.05*	-	-1.75	-	-3.83*	-4.59*	-2.92
q (no trend)	-0.97	-	-1.46	-	-1.80	-0.29	-0.38
Δq	-7.83*	-	-4.51*	-	-6.39*	-8.42*	-6.86*
ep (with trend)	-2.66	-1.80	-2.13	-1.97	-1.44	-3.12	-2.53
ep (no trend)	0.04	0.38	-0.24	-1.13	1.49	-2.00	-1.11
Δep	-7.24*	-8.61*	-6.00*	-2.86*	-6.37*	-4.79*	-6.99*
ρ^S(with trend)	-2.91	-3.39*	-3.37*	-	-3.11	-2.89	-2.28
ρ^S (no trend)	-1.57	-3.18*	-2.51	-	-1.48	-2.84*	-1.29
$\Delta\rho^S$	-8.36*	-4.45*	-7.94*	-	-4.57*	-5.93*	-7.95*
ρ^L (with trend)	-1.43	-	-	-	-	-0.69	-3.51*
ρ^L (no trend)	-1.28	-	-	-	-	-1.50	-0.70
$\Delta\rho^L$	-7.08*	-	-	-	-	-8.38*	-6.92*

Variable	*Switzerland*	*Thailand*	*Turkey*	*United Kingdom*	*United States*
y (with trend)	-2.67	-1.36	-2.73	-2.80	-2.45
y (no trend)	1.50	1.29	1.47	-0.87	1.23
Δy	-5.19*	-3.09*	-7.75*	-2.97*	-4.74*
π (with trend)	-4.67*	-3.07	-2.25	-2.65	-1.34
π (no trend)	-3.52*	-2.50	-1.57	-1.41	0.04
$\Delta\pi$	-10.67*	-7.78*	-7.84*	-8.25*	-8.64*
q (with trend)	-2.11	-1.79	-	-1.77	-1.75
q (no trend)	-0.65	-1.57	-	-0.75	-0.61
Δq	-6.57*	-5.02*	-	-7.13*	-6.24*
ep (with trend)	-2.49	-2.47	-1.35	-3.29*	-
ep (no trend)	-0.15	-0.70	-0.37	-0.10	-
Δep	-7.48*	-5.55*	-5.97*	-5.59*	-
ρ^S(with trend)	-2.20	-3.69*	-1.48	-3.35*	-3.76*
ρ^S (no trend)	-2.08	-2.11	-1.49	-1.18	-1.65
$\Delta\rho^S$	-4.93*	-6.29*	-9.08*	-6.63*	-3.70*
ρ^L (with trend)	-2.58	-	-	-3.03	-3.98*
ρ^L (no trend)	-1.70	-	-	-0.43	-1.51
$\Delta\rho^L$	-5.91*	-	-	-7.98*	-5.83*

An asterisk denotes rejection of the null hypothesis of a unit root with a 5% level of significance.

Table B.2 WS-ADF test statistics for foreign variables in the GVAR

Variable	*Argentina*	*Australia*	*Brazil*	*Canada*	*Chile*	*China*	*Euro area*
y^* (with trend)	-1.29	-1.52	-1.50	-3.38*	-1.49	-2.78	-1.39
y^* (no trend)	2.04	1.91	1.66	1.47	1.99	1.62	1.54
Δy^*	-4.92*	-4.53*	-4.48*	-4.73*	-3.86*	-4.81*	-4.41*
π^* (with trend)	-2.88	-2.78	-3.54*	-2.02	-2.78	-3.61*	-3.51*
π^* (no trend)	-2.62*	-1.13	-2.47	-0.17	-2.23	-2.10	-2.17
$\Delta\pi^*$	-5.93*	-6.79*	-11.67*	-8.34*	-7.97*	-6.48*	-9.12*
q^* (with trend)	-2.54	-2.58	-3.14	-1.95	-2.71	-2.68	-2.48
q^* (no trend)	-0.47	-1.03	-0.81	-0.60	-1.03	-0.94	-0.57
Δq^*	-6.88*	-7.00*	-7.41*	-6.43*	-6.98*	-7.04*	-6.97*
ep^* (with trend)	-2.03	-2.80	-1.85	-2.86	-3.01	-2.19	-3.43*
ep^* (no trend)	-1.40	-0.14	-0.61	-0.71	-2.12	-1.26	-0.19
Δep^*	-3.72*	-5.08*	-7.87*	-4.32*	-8.28*	-3.97*	-7.73*
ρ^{S*} (with trend)	-2.73	-3.09	-3.19	-3.68*	-2.44	-2.82	-2.15
ρ^{S*} (no trend)	-2.58*	-1.28	-1.42	-1.28	-2.05	-1.58	-1.31
$\Delta\rho^{S*}$	-10.15*	-5.20*	-14.37*	-3.80*	-10.75*	-5.82*	-10.53*
ρ^{L*} (with trend)	-2.72	-3.61*	-2.85	-3.96*	-2.78	-3.20	-3.73*
ρ^{L*} (no trend)	-0.92	-0.67	-0.94	-1.14	-0.87	-1.21	-0.77
$\Delta\rho^{L*}$	-5.56*	-5.57*	-5.51*	-5.73*	-5.56*	-5.13*	-5.76*

Variable	*India*	*Indonesia*	*Japan*	*Korea*	*Malaysia*	*Mexico*	*New Zealand*
y^* (with trend)	-1.68	-2.33	-0.69	-1.44	-2.64	-3.41*	-2.59
y^* (no trend)	1.65	2.07	1.55	0.77	1.48	1.50	0.70
Δy^*	-4.31*	-4.59*	-4.65*	-3.65*	-5.03*	-4.89*	-4.49*
π^* (with trend)	-2.89	-3.08	-3.74*	-3.42*	-2.69	-3.41*	-2.47
π^* (no trend)	-1.20	-1.41	-0.87	-2.05	-1.42	-1.11	-0.62
$\Delta\pi^*$	-7.36*	-6.71*	-6.98*	-6.57*	-7.00*	-10.86*	-7.10*
q^* (with trend)	-2.35	-2.39	-2.67	-2.36	-2.69	-1.95	-2.85
q^* (no trend)	-0.74	-0.98	-0.70	-0.79	-0.97	-0.62	-0.85
Δq^*	-6.94*	-7.13*	-7.03*	-6.98*	-7.08*	-6.40*	-6.94*
ep^* (with trend)	-1.63	-1.74	-1.71	-2.16	-1.84	-2.42	-3.10
ep^* (no trend)	-0.50	1.40	0.00	1.07	-0.08	-2.48	-0.07
Δep^*	-7.34*	-8.74*	-4.84*	-7.79*	-6.66*	-4.06*	-4.86*
ρ^{S*} (with trend)	-2.34	-2.93	-2.78	-2.76	-3.49*	-3.60*	-3.18
ρ^{S*} (no trend)	-1.08	-1.52	-1.10	-1.13	-1.63	-1.48	-1.46
$\Delta\rho^{S*}$	-6.93*	-4.64*	-6.26*	-5.91*	-4.49*	-5.60*	-4.40*
ρ^{L*} (with trend)	-2.76	-3.44*	-3.13	-3.33*	-2.72	-3.86*	-2.62
ρ^{L*} (no trend)	-0.82	-0.89	-0.88	-0.94	-0.79	-1.12	-0.90
$\Delta\rho^{L*}$	-5.62*	-5.17*	-5.68*	-5.26*	-5.35*	-5.56*	-5.52*

Variable	*Norway*	*Peru*	*Philippines*	*Saudi Arabia*	*Singapore*	*South Africa*	*Sweden*
y^* (with trend)	-3.02	-1.69	-2.04	-2.27	-2.46	-2.04	-2.93
y^* (no trend)	0.63	1.94	0.99	0.79	1.77	0.53	1.33
Δy^*	-4.30	-4.61*	-4.60*	-4.38*	-4.96*	-3.72*	-3.39*
π^* (with trend)	-2.34	-2.94	-3.14	-3.03	-3.89*	-3.40*	-2.47
π^* (no trend)	-0.63	-2.39	-1.32	-1.87	-1.03	-1.47	-0.58
$\Delta\pi^*$	-6.71	-9.14*	-7.07*	-7.22*	-7.57*	-6.61*	-6.85*
q^* (with trend)	-2.73	-2.28	-2.29	-2.42	-2.78	-2.41	-2.56
q^* (no trend)	-0.84	-0.60	-0.97	-0.89	-0.83	-0.87	-0.82
Δq^*	-6.92	-6.95*	-6.98*	-7.16*	-7.23*	-7.20*	-6.96*
ep^* (with trend)	-2.40	-2.23	-1.82	-3.30*	-1.54	-2.73	-2.68
ep^* (no trend)	-0.10	-1.08	0.51	-3.26*	-0.64	-1.82	-0.17
Δep^*	-6.86	-4.43*	-4.54*	-3.82*	-4.67*	-4.63*	-6.89*
ρ^{S*} (with trend)	-2.58	-2.64	-2.75	-2.37	-3.27*	-2.47	-2.39
ρ^{S*} (no trend)	-1.00	-2.14	-1.16	-1.56	-1.45	-1.26	-0.87
$\Delta\rho^{S*}$	-5.09	-11.58*	-7.05*	-8.95*	-4.98*	-6.17*	-5.75*
ρ^{L*} (with trend)	-2.72	-3.80*	-2.90	-2.80	-2.68	-2.76	-2.43
ρ^{L*} (no trend)	-0.64	-0.91	-0.80	-0.77	-0.82	-0.82	-0.84
$\Delta\rho^{L*}$	-5.80	-5.54*	-5.48*	-5.37*	-5.56*	-5.45*	-5.61*

Variable	*Switzerland*	*Thailand*	*Turkey*	*United Kingdom*	*United States*
y^* (with trend)	-2.59	-2.58	-2.59	-3.15	-1.78
y^* (no trend)	1.07	1.71	1.43	1.43	1.56
Δy^*	-4.56*	-4.57*	-4.42*	-4.63*	-4.26*
π^* (with trend)	-2.35	-2.68	-2.96	-2.32	-3.08
π^* (no trend)	-0.50	-1.40	-1.65	-0.43	-1.01
$\Delta\pi^*$	-7.00*	-7.40*	-6.61*	-7.28*	-9.58*
q^* (with trend)	-2.36	-2.60	-2.43	-2.64	-3.30*
q^* (no trend)	-0.86	-0.87	-0.75	-0.73	-0.84
Δq^*	-6.79*	-7.07*	-6.79*	-6.96*	-7.26*
ep^* (with trend)	-2.54	-2.83	-2.60	-2.31	-2.09
ep^* (no trend)	-0.13	-1.67	-0.94	-0.13	1.01
Δep^*	-6.81*	-4.58*	-7.28*	-6.72*	-7.11*
ρ^{S*} (with trend)	-2.38	-2.57	-2.30	-2.30	-1.63
ρ^{S*} (no trend)	-0.97	-1.29	-1.04	-0.88	-1.01
$\Delta\rho^{S*}$	-5.45*	-5.68*	-9.04*	-6.02*	-11.46*
ρ^{L*} (with trend)	-2.52	-2.57	-2.53	-2.44	-3.23
ρ^{L*} (no trend)	-0.88	-0.81	-0.91	-0.91	-0.93
$\Delta\rho^{L*}$	-5.42*	-5.28*	-5.52*	-5.58*	-4.92*

An asterisk denotes rejection of the null hypothesis of a unit root with a 5% level of significance.

Table B.3 WS-ADF test statistics for global variable in the GVAR

Variable	*Global*
p^{oil} (with trend)	-1.28
p^{oil} (no trend)	-1.00
Δp^{oil}	-6.49*

An asterisk denotes rejection of the null hypothesis of a unit root with a 5% level of significance.

B.2 PARAMETER STABILITY TEST RESULTS

Table B.4 summarises the results of various tests for parameter constancy.

Table B.4 Number of rejections of the null hypothesis of parameter stability for each domestic variable across the country-specific models (Percentage of rejections in brackets)

Test statistics	y	π	q	ep	ρ^S	ρ^L	*Total number*
PK_{sup}	8 (31%)	4 (15%)	2 (11%)	2 (8%)	4 (16%)	2 (17%)	22 (17%)
PK_{msq}	8 (31%)	3 (12%)	1 (5%)	2 (8%)	2 (8%)	1 (8%)	17 (13%)
$\aleph$	7 (27%)	4 (15%)	4 (21%)	9 (36%)	2 (8%)	4 (33%)	30 (23%)
Robust-$\aleph$	4 (15%)	1 (4%)	0 (0%)	7 (28%)	1 (4%)	3 (25%)	16 (12%)
QLR	7 (27%)	10 (38%)	8 (42%)	11 (44%)	13 (52%)	6 (50%)	55 (41%)
Robust-*QLR*	2 (8%)	4 (15%)	4 (21%)	8 (32%)	1 (4%)	4 (33%)	23 (17%)
MW	5 (19%)	5 (19%)	6 (32%)	10 (40%)	2 (8%)	5 (42%)	33 (25%)
Robust-*MW*	3 (12%)	5 (19%)	4 (21%)	9 (36%)	1 (4%)	3 (25%)	25 (19%)
APW	8 (31%)	10 (38%)	8 (42%)	11 (44%)	13 (52%)	6 (50%)	56 (42%)
Robust-*APW*	2 (8%)	5 (19%)	4 (21%)	8 (32%)	2 (8%)	5 (42%)	26 (20%)

The test statistics explained by Smith and Galesi (2011) are used. PK_{sup} is the Ploberger and Krämer maximal OLS cumulative sum (CUSUM) statistics, PK_{msq} is the mean square variant of PK_{sup}, and $\aleph$ is the Nyblom test statistic for time-varying parameters. Sequential Wald statistics for a one-time structural change at an unknown point include the Quandt likelihood ratio (*QLR*) statistic, the Hansen mean Wald statistic (*MW*), and the Andrews and Ploberger Wald (*APW*) statistic. Test statistics with the prefix robust are the heteroscedasticity-robust versions of the relevant tests.

All the test statistics are compared with bootstrapped critical values at a 5% significance level to determine the number of rejections of the null hypothesis of stable parameters.

B.3 BOOTSTRAPPED GIRFS

Figure B.1 to Figure B.4 plot the GIRFs for one standard deviation increases in GDP in China and the US respectively, first for increases in 2009 and then for increases in 1995. The graphs include 90% bootstrapped confidence intervals.

Figure B.1 GIRFs for one standard deviation increase in Chinese GDP in 2009 with 90% bootstrapped confidence intervals

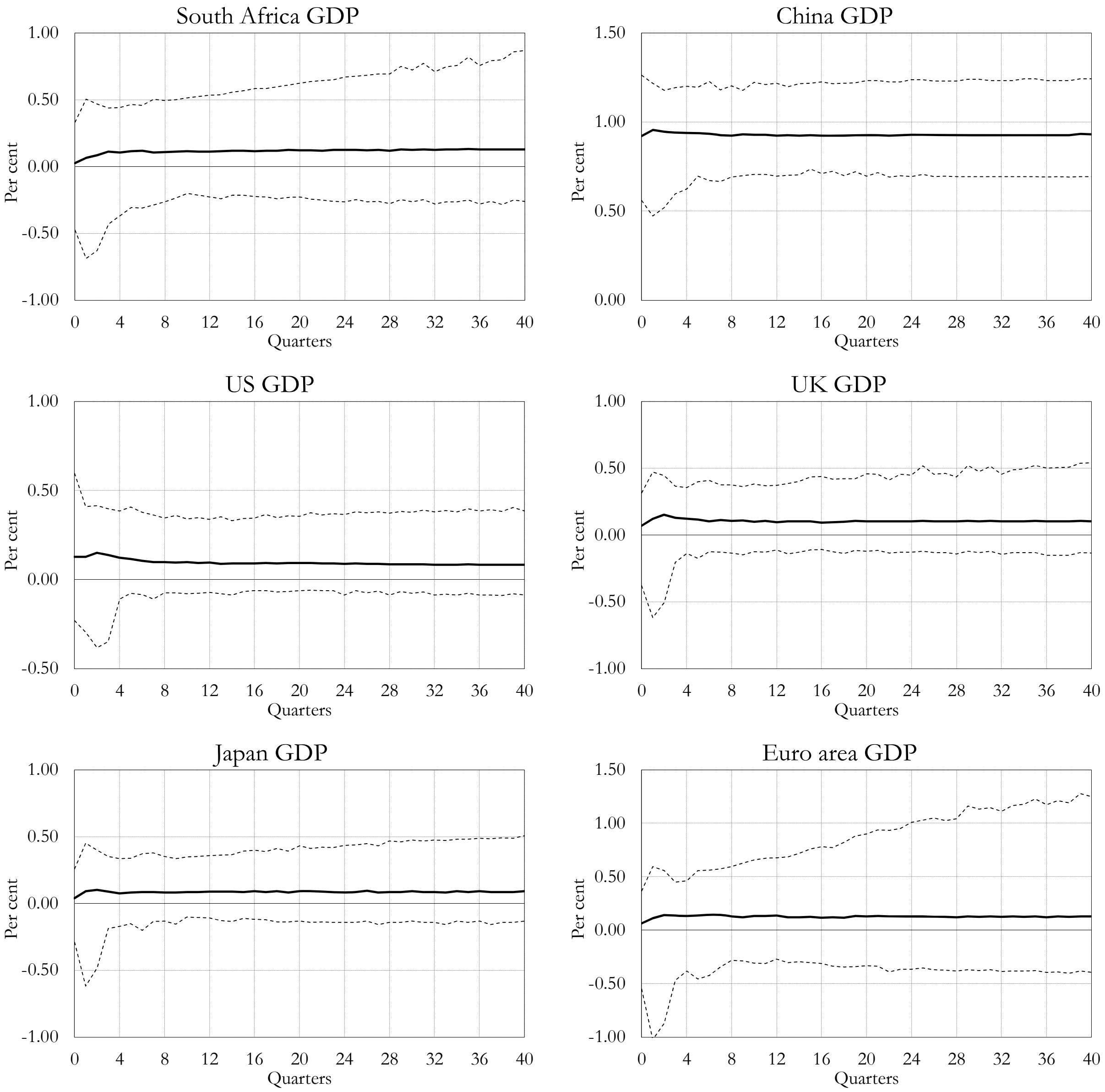


Figure B.2 GIRFs for one standard deviation increase in Chinese GDP in 1995 with 90% bootstrapped confidence intervals

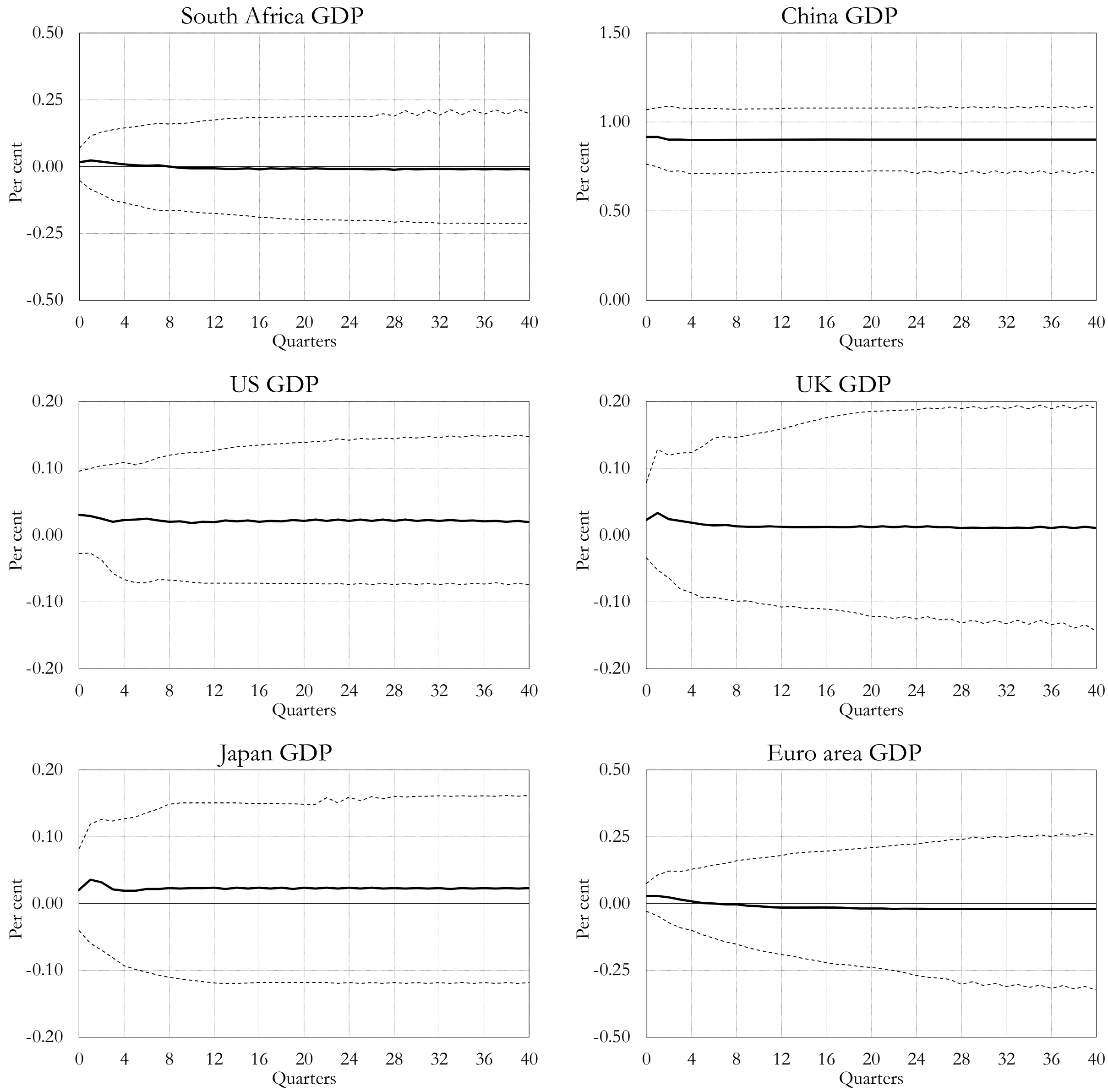


Figure B.3 GIRFs for one standard deviation increase in US GDP in 2009 with 90% bootstrapped confidence intervals

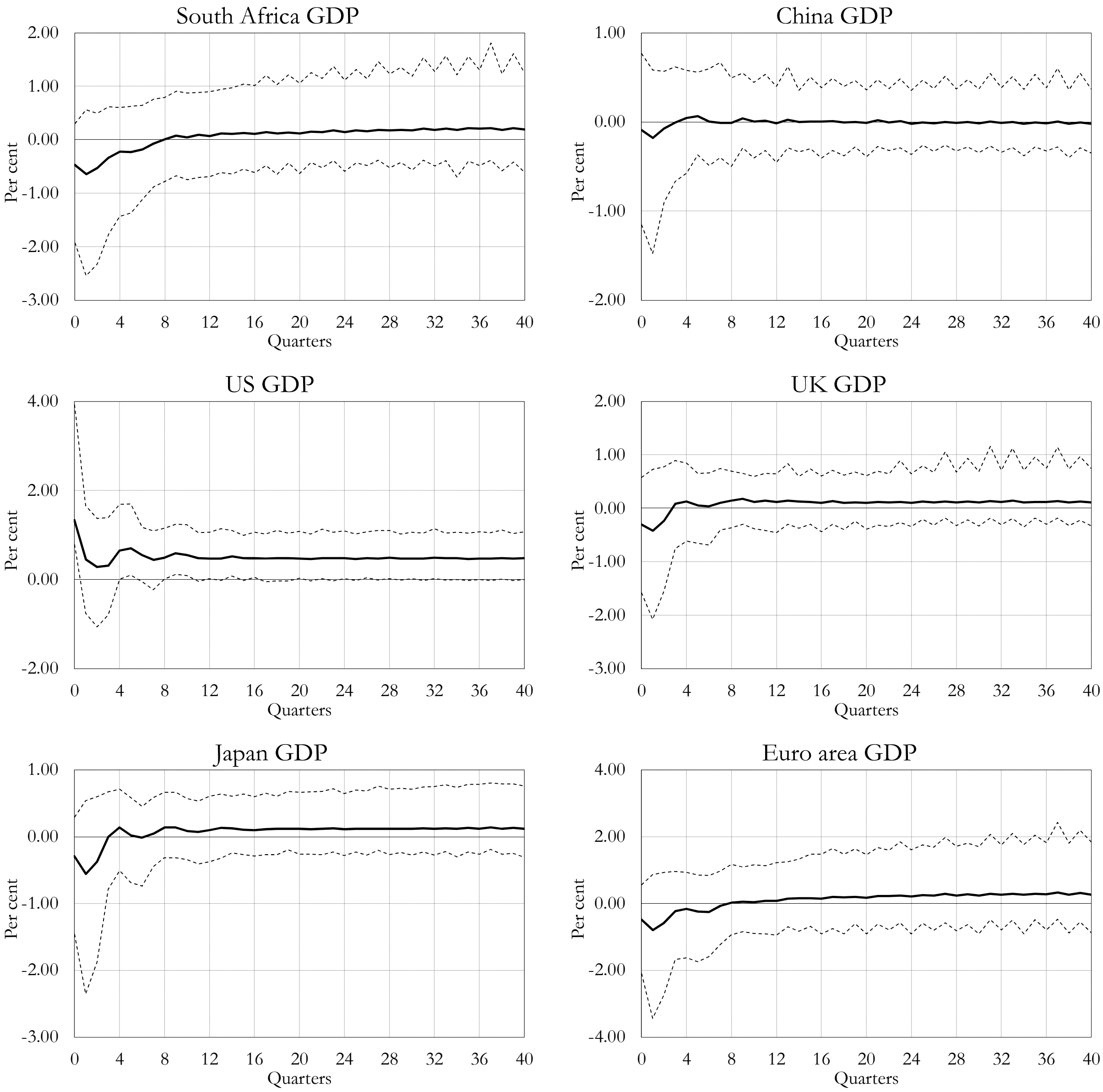
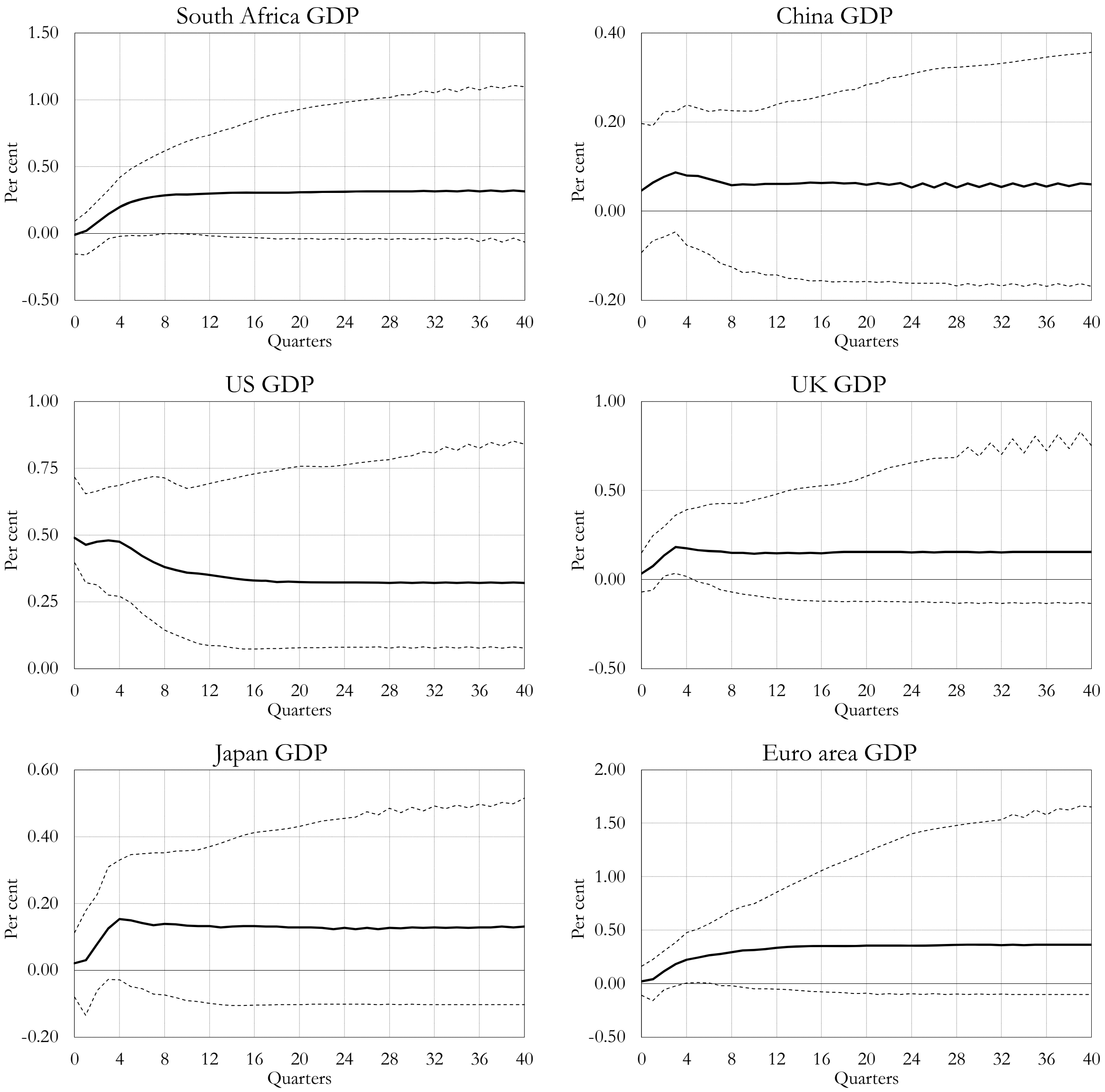


Figure B.4 GIRFs for one standard deviation increase in US GDP in 1995 with 90% bootstrapped confidence intervals



APPENDIX C

Appendix to Chapter 4

C.1 ROOT MEAN SQUARED FORECAST ERROR (RMSFE)

The h-quarter ahead forecast error for each variable of each model is $e_t(h) = y_{t+h} - \hat{y}_{t+h|t}$, where y_{t+h} is the actual value of the variable and $\hat{y}_{t+h|t}$ is the forecast of the variable.

The h-quarter ahead RMSFE is

$$RMSFE(h, n) = 100\sqrt{n^{-1}\sum_{t=T}^{T+n-1} e_t^2(h)},$$

with n the forecast sample size.

C.2 MODIFIED DIEBOLD-MARIANO TEST

Harvey *et al.* (1997) suggest a modified version of the Diebold-Mariano test (Diebold & Mariano, 1995) for the evaluation of forecasts. The null hypothesis of both the original and the modified tests is that the forecast accuracy of two models is equal, implying that the forecast mean squared errors of two models are equivalent. The original Diebold-Mariano test tends to over-reject the null hypothesis of equal forecasts (that is, it has size problems) when the sample size is small and when the forecasts are more than one-period ahead. An advantage of the modification is that it has better size properties for small samples and for longer forecast horizons. It also does not require the assumption that forecasts are unbiased.

The formula for the modified Diebold-Mariano test statistic is:

$$S_1^* = \left[\frac{n + 1 - 2h + n^{-1}h(h-1)}{n}\right]^{1/2} S_1,$$

where S_1 is the original Diebold-Mariano test statistic. The modified test statistic is compared to critical values of the Student's t distribution with $(n-1)$ degrees of freedom. The sample size is n and the forecast horizon is h.