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THE GVAR HANDBOOK

Structure and Applications of a Macro Model of the Global Economy for Policy Analysis

Edited by Filippo di Mauro & M. Hashem Pesaran

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Introduction: An overview of the GVAR approach and the handbook

Filippo di Mauro and M. Hashem Pesaran

Macroeconomic policy analysis and risk management require taking account of the increasing interdependencies that exist across markets and economies. National economic issues need to be considered from global as well as domestic perspectives. This invariably means that many different channels of transmission must be taken into account. These could be common observed or unobserved global factors such as oil or food prices, technological and political developments that are pervasive, or they could be specific national or sectoral factors. Even after allowing for such effects, there might still be residual interdependencies, due to policy or trade spillover effects, to be taken into account. Allowing for all these channels of interactions in forecasting and policy analysis presents us with the challenging task of modelling a complex, high-dimensional system.

The chapters in this volume consider the analyses of such interdependencies using the GVAR (global vector autoregression) approach advanced in Pesaran, Schuermann and Weiner (2004, PSW). GVAR was originally developed in the aftermath of the 1997 East Asian financial crisis to quantify the effects of changing macroeconomic conditions (at national and global levels) on the loss distribution of loan portfolios held by large banks and other financial institutions. At that time the financial industry's approach to modelling credit risk primarily focused on unconditional credit loss distributions and was not suited to answering counterfactual questions that were being posed in the light of the Asian crisis.[1] For example, many banks were interested in learning about the consequences of similar crises elsewhere

[1] The state of the art in the industry at the time was summarized by Gupton, Finger, and Bhatia (1997).

in the global economy for the distribution of their loan portfolios that were often subject to significant global exposures. Almost all major financial institutions are ultimately exposed to macroeconomic fluctuations in the global economy, and although their portfolios are typically large enough that idiosyncratic risk is diversified away, it was clear that they remained highly exposed to systematic risk from adverse common global or regional shocks. To quantify the possible effects of such shocks on loss distributions one needed a compact global macroeconometric model to generate the necessary counterfactual scenarios.

Although a few large global models existed, such models were estimated/calibrated with annual data and tended to be very large and difficult to use for simulation analysis. The existing models were also often incomplete and did not present a closed global system, which is ultimately required for *ex ante* forecasting and for generation of loss distributions under different counterfactual scenarios.[2] The GVAR framework was developed specifically to fill this gap in global modelling and simulation analysis. Its methodological contribution lay in developing a practical and parsimonious procedure for dealing with the curse of dimensionality in a theoretically coherent and statistically consistent manner.

Whilst the GVAR model was initially developed as a tool for credit risk analysis, it soon became clear that it has numerous other applications. It is particularly suited to the analysis of the transmission of shocks from one market, country, or region to other markets and economies. It readily allows modelling of long-run relations such as purchasing power parity, and uncovered interest parity that relate domestic to foreign variables. It can be used for *ex ante* forecasting of global macrovariables in an internally consistent manner.

The GVAR model is composed of a large number of unit-specific models. In many applications the units are countries or regions. But they could equally be counties, municipalities, industries, or sectors of a given economy. Interactions across units are modelled by relating the variables internal to the unit to those that affect the unit under consideration externally. In the context of macroeconomic models the core domestic variables (such as real output, inflation, interest rates, real equity prices, and the exchange rate) are related to global observed variables, such as international energy and food prices, and foreign-specific variables (denoted as 'starred' variables). Foreign variables are constructed as weighted averages of foreign variables that correspond to the domestic variable in question, typically using trade weights. The 'curse of dimensionality' is overcome by estimating the country-specific

[2] A brief overview of the alternative global modelling approaches is provided in PSW, with a more recent updated account provided by Granger and Jeon (2007).

error-correcting models separately, conditional on the foreign variables that are treated as weakly exogenous. The assumption of weak exogeneity is typically upheld when tested. This assumption is also seen to be a priori plausible considering that the size of most economies compared to the global economy (possibly with the exception of the US) is relatively small, often not exceeding 5% of world GDP. The US economy is treated differently to take account of its importance in the global economy, particularly in equity and bond markets. Country-specific models are then solved simultaneously for all the endogenous variables in the global model. Long-run properties of the global model are based on market arbitrage and stock-flow equilibrium conditions applied to the individual economies. Short-run dynamics are typically left unconstrained. Shocks to one country can have marked effects on other countries, depending on their size and the patterns of their trade.

Early empirical applications, focusing on the euro area, showed that the GVAR model is quite effective in dealing with common factor interdependencies and international co-movements of business cycles. Unlike the very high cross-sectional correlation of the core variables in the GVAR model, the residuals from the GVAR are hardly correlated across countries, with the notable exception of exchange rates. It was also found that financial shocks (equity and bond prices) tended to be transmitted much faster than shocks to real output and/or inflation. Equity and bond markets seemed to be far more synchronous as compared to the foreign exchange markets. The effects of output shocks across countries turned out to be less synchronous than inflation shocks, which were still less synchronous than the effects of shocks to financial markets. These stylized features continue to hold using more recent data that covers the 2008 great recession (see Chapter 2).

Since its introduction, the GVAR has stimulated a large and growing literature, with contributions from academics as well as professional economists. There is a large number of refereed journal articles that make use of the GVAR modelling approach, and the work on GVAR has been cited extensively in specialized literature and widely used—in one version or another—by economic practitioners and analysts.[3]

This volume is the first systematic attempt to bring together a large number of different applications of the GVAR in the literature. In so doing, however, the book also aims at a broader readership of practitioners and policymakers and not solely the specialized econometricians. Therefore it uses a language and format that is less technical, and hopefully more accessible to a larger readership, without losing sight of rigour and clarity of the analysis and the exposition.

[3] There are over 1400 Google citations for 'GVAR modelling', and 299 Google citations for the PSW paper.

The objectives of the book are threefold: (i) to show how the original GVAR model has evolved over the years; (ii) to report on the applications and extensions made by several contributors; and, (iii) ultimately, to show how powerful the model can be as a tool for forecasting and policy analysis.

The rest of the volume begins with **Chapter 2** (written by Filippo di Mauro and Vanessa Smith), which presents a GVAR model estimated for 26 countries, the euro area being treated as a single economy, over the period 1979–2011. This chapter updates the estimates initially reported in Dées, di Mauro, Pesaran, and Smith (2007) using a new data set compiled by Gang Zhang, Ambrogio Cesa Bianchi, and Alessandro Rebucci at the Inter-American Development Bank. The detailed description of the original model, as well as the new data set, is available on the Web: <https://sites.google.com/site/gvarmodelling/>.

A GVAR toolbox can also be freely downloaded from the above link that provides an easy-to-use interface for implementing the GVAR code. The new results provided in this chapter broadly corroborate the earlier results, despite the recent extreme financial and economic developments in the world economy. Using average pairwise cross-section error correlations, the GVAR approach is shown to be quite effective in dealing with the common factor interdependencies and international co-movements of business cycles. A number of simulation results is also provided that show the effects of real equity and US GDP shocks on different countries and variables in the global economy.

The remaining contributions are broadly divided into three parts. **Part I** (Chapters 3–8) focuses on international transmission and forecasting; **Part II** (Chapters 9–12) on applications to finance; and **Part III** (Chapters 13–18) considers a number of regional applications and adds a conclusion.

1.1 International transmission and forecasting

Chapter 3 (Anthony Garratt, Kevin Lee, and Kalvinder Shields) is concerned with the measurement of output gaps across countries. This chapter proposes a measure of the natural output Gap extracted from the relationship between released and expected outputs, with output expectations data obtained from published forecasts. The gap measure has the attractive feature that it abstracts from the effects of any short-lived disturbances to focus on longer-lived fluctuations around a sustainable trend. Natural gap measures for the G7 economies are derived from a GVAR representation of the actual and expected output series. The GVAR model captures the interdependencies of actual output movements across the countries and also identifies and takes into account the effect of short-lived innovations experienced at home and abroad.

The nature and size of the interdependence of the G7 countries' economic performance is described by comparing models estimated with and without the cross-country feedbacks in the actual series and in expectations. The cross-country interactions generate complex dynamic responses in countries' outputs to national and global innovations and these are illustrated through impulse response analysis. The uncertainties surrounding the measures of the countries' gaps are conveyed through the measure of gap densities (complementing the more usual point estimates), and a novel means of characterizing global recession is suggested based on the joint density describing the economies' output gaps derived on the basis of the GVAR model.

Chapter 4 (Ron Smith) presents a multi-country new-Keynesian model built up following the GVAR modelling approach. This model aims to analysing the international transmission of shocks by identifying their nature and origin. More precisely, it is used to estimate the effect of specific supply, demand, and monetary policy shocks. The model is estimated for 33 countries, each country having an open-economy version of the standard three-equation forward-looking new-Keynesian model, with a Phillips curve determining inflation, an IS curve determining output, and a Taylor rule determining interest rates, plus an equation for the real effective exchange rate. This new-Keynesian model is considered as being structural (in the sense of the DSGE modelling approach), since under certain standard theoretical assumptions, its parameters can be related to 'deeper' parameters of technology and tastes. Overall, this modelling exercise shows that it is possible to estimate, solve, and simulate a forward-looking multi-country new-Keynesian model and to use this to estimate the effects of identified supply, demand, and monetary policy shocks.

Chapter 5 (Alessandro Galesi and Marco Lombardi) takes a policy perspective on the recent commodity price gyrations, and considers the extent to which oil and food price shocks affect the general level of price inflation and real output. Using a monthly GVAR, this chapter first examines the short-run inflationary effects of oil and food price shocks on a given set of countries. Second, it assesses the importance of inflation linkages among countries, by disentangling the geographical sources of inflationary pressures for each region. Generalized impulse response functions reveal that the direct inflationary effect of oil price shocks is more pronounced for developed countries as compared to their effects on emerging economies. Food price increases also have significant inflationary direct effects, but especially for emerging economies. Moreover, significant second-round effects are observed in some countries. Generalized forecast error variance decompositions indicate that considerable linkages through which inflationary pressures spill over exist across regions. In addition, a considerable part of the observed headline inflation increases is attributable to foreign sources for the vast majority of the regions.

In **Chapter 6** (Sandra Eickmeier and Tim Ng), the GVAR approach is used to model financial markets and institutions as sources of cross-border financial shocks. The authors study the effects of credit supply shocks originating in the US, euro area, and Japan on those economies and on 23 others. They find that cross-border financial spillovers are particularly important in generating international financial and economic dynamics. This result is not limited to the 2007–09 crisis episode in the sample. As part of this work, the chapter examines in detail how using different types of cross-border financial asset and liability exposures in the weighting schemes for foreign variables affects the fit of the GVAR to the data. It is found that using inward FDI exposures fits the data best, and substantially better than trade weights. Using the best-fitting GVAR as a benchmark, US credit supply shocks are found to have strong effects on a range of real and financial variables in other countries. In comparison, the international effects of Japanese and euro-area credit supply shocks are generally weaker. An interesting result is that the exchange rate responses suggest 'flight to quality' behaviour towards the US dollar in response to credit supply shocks originating in the US, the euro area, or Japan.

Chapter 7 (Matthew Greenwood-Nimmo, Viet Hoang Nguyen, and Yongcheol Shin) demonstrates the usefulness of the GVAR modelling framework as a tool for scenario-based forecasting and counterfactual analysis. Working with the GVAR model developed by Greenwood-Nimmo, Nguyen and Shin (2012), the chapter first shows how probabilistic forecasting can be applied to the analysis of global imbalances. Probabilistic forecasting involves evaluating the conditional probability that a given event or combination of events will occur over a defined horizon by means of model-based simulations. To illustrate the usefulness of this approach, the authors develop a simple four-way probabilistic classificatory system built around the notions of balancing improvement in the trade balance, unbalancing improvement, balancing deterioration, and unbalancing deterioration. They then extend a similar approach in a counterfactual context by constructing a range of scenarios as linear combinations of generalized impulse responses. They conclude that GVAR models are particularly well-suited to scenario-based analyses such as the one depicted in the chapter, as they have the potential to analyse singularly rich data sets that allow the modeller to construct a wide range of policy-relevant scenarios.

Chapter 8 (Vanessa Smith) considers the problem of forecasting economic and financial variables across a large number of countries in the global economy. To this end, GVAR models previously estimated by Dées, di Mauro, Pesaran, and Smith (2007) and Dées, Holly, Pesaran, and Smith (2007) over the period 1979q1–2003q4 are used to generate out-of-sample forecasts one and four quarters ahead for real output, inflation, real equity prices, exchange rates, and interest rates over the period 2004q1–2005q4. Forecasts are obtained for 134 variables from 26 regions, which are made up of 33 countries and cover about 90% of the world output. The forecasts are compared to typical benchmarks: univariate autoregressive and random walk models. Building on the forecast combination literature, the effects of model and estimation uncertainty on forecast outcomes are examined by pooling forecasts obtained from different GVAR models estimated over alternative sample periods. Given the size of the modelling problem, and the heterogeneity of the economies considered—industrialized, emerging, and less developed countries—as well as the very real likelihood of possibly multiple structural breaks, averaging forecasts across both models and windows makes a significant difference. Indeed, the double-averaged GVAR forecasts perform better than the benchmark competitors, especially for output, inflation, and real equity prices.

1.2 Finance applications

Chapter 9 (Silvia Lui and James Mitchell) is motivated by the fact that quarterly euro-area GDP data are published at a lag of about 45 days: this, in turn, hinders policymaking in real-time. Accordingly, the chapter evaluates the quality of GDP nowcasts produced at a shorter lag by exploiting available monthly indicator variables. Given that euro-area GDP is the aggregation of national GDP data, and since publication lags vary both by country and by indicator variable, the authors use the GVAR to accommodate both cross-country and cross-variable dependencies when nowcasting. The GVAR, by efficiently conditioning on all available disaggregate information, minimizes the root mean squared errors of the nowcast. Nowcasts for the euro area are produced within-quarter, reflecting the differing publication lags and informational content of GDP, industrial production, and qualitative survey data across the euro-area countries. Using a novel real-time data set for the euro area, and its constituent countries, in real-time simulations the proposed GVAR nowcasts are found to be more accurate than the commonly used 'direct' approach to nowcasting an aggregate. The GVAR's nowcasts are, however, less accurate than those from the 'indirect' approach, which itself is a restricted GVAR. This motivates forecast combination as a means of rendering GVAR nowcasts more robust to 'structural instabilities'.

Chapter 10 (Alexander Al-Haschimi and Stéphane Dées) attempts to link systemic risk indicators at a firm level to global macroeconomic data in a coherent manner while allowing for feedback effects from the firm-level data to the macroeconomy. The chapter builds a panel combining firm-level indicators with macroeconomic variables in order to quantify the macrofinancial linkages. The chapter shows how the GVAR can incorporate many of the economic features that gained prominence during the recent period of financial distress. It does so by analysing two specific existing applications. Castren et al. (2010) show how the GVAR can be linked to expected default frequencies of euro-area firms to quantify the impact of global shocks on the firm's default risk. In this approach, the GVAR captures the international transmission of financial and economic shocks that were key avenues for the dispersion of financial instability during the recent crisis. Chen et al. (2010) further developed this model by endogenizing default frequencies in the GVAR such that it captures the two-way feedback between firm-level distress and macroeconomic dynamics. Overall, the GVAR framework proves to be a flexible and policy-relevant tool for stress-testing exercises. As outlined at the end of the chapter, accounting for firm-level heterogeneity appears to be one avenue for further research.

Chapter 11 (Carlo Favero) starts from the observation that the main driver of yield differentials (spreads of 10-year yields on German bunds) in the euro area is default risk and there is a clear time-varying co-movement among differentials. The main issue is the weights to be attached to fiscal fundamentals and 'market sentiment' in the determination of yield spreads. The chapter addresses this issue by extending the framework of the basic GVAR to propose a nonlinear global VAR model of the spreads on bunds. In the proposed specification the dynamics of each spread is determined by its fundamentals relative to the German ones and a global variable that models the exposure of each country's spread to the other spreads in the euro area in terms of the 'distance' between their fiscal fundamentals. The global variable for each country's spreads on Germany is determined by a weighted average of spreads in order to make the factor more dependent on the spreads of those countries that are more similar in terms of fiscal fundamentals. Using the distance in terms of fiscal fundamentals makes the global variable country-specific and the weights more volatile than in the standard GVAR based on trade weights. The changing weights, related to the changing expectations for fiscal fundamentals, have the potential to explain the changing correlation among spreads. The specification explicitly allows for a nonlinear relationship between spreads and fiscal fundamentals.

Chapter 12 (Christiane Nickel and Isabel Vansteenkiste) illustrates the international spillover effects of fiscal shocks. The focus of the analysis is on the impact of fiscal spending shocks on financial variables (namely equity prices, government bond yields, and corporate bond yields), using the basic GVAR methodology applied to eight countries using quarterly data over the period 1980q1–2008q4. Overall, the results suggest that fiscal shocks have significant domestic and international spillover effects on financial variables. A shock to government consumption, in a large country with perceived risk-free government bonds, results in an increase in equity prices and government bond yields both domestically and internationally. By contrast, in the case of the peripheral countries, a shock to government consumption results in an increase in domestic government bond yields, whereas it reduces yields in large neighbouring countries with risk-free government bonds. Equity prices in peripheral countries meanwhile decline when fiscal spending increases. Finally, a shock to government bond yields spills over to the domestic and international corporate bond markets, in particular when the shock originates in a large country.

1.3 Regional applications

Following the strong impacts of the crisis, **Chapter 13** (Ambrogio Cesa-Bianchi, Hashem Pesaran, Alessandro Rebucci, and TengTeng Xu) investigates how changes in trade linkages between China, Latin America, and the rest of the world have altered the transmission mechanism of international business cycles to Latin America. Evidence based on a GVAR model for five large Latin American economies and all major advanced and emerging economies of the world shows that the long-term impact of a China GDP shock on the typical Latin American economy has increased by three times since the mid-1990s. At the same time, the long-term impact of a US GDP shock has halved, while the transmission of shocks to Latin America and the rest of emerging Asia (excluding China and India) GDP has not undergone any significant change. Contrary to common wisdom, the chapter shows that these changes owe more to the changed impact of China on Latin America's traditional and largest trading partners than to increased direct bilateral trade linkages boosted by the decade-long commodity price boom. These findings help to explain why Latin America did so well during the global crisis, but point to the risks associated with a deceleration in China's economic growth in the future for both Latin America and the rest of the world economy. The evidence reported also suggests that the emergence of China as an important source of world growth might be the driver of the so-called 'decoupling' of emerging-market business cycle from that of advanced economies reported in the existing literature.

Chapter 14 (David Fielding, Kevin Lee, and Kalvinder Shields) constructs a structural macroeconometric model for member states of the West African

Economic and Monetary Union (UEMOA). Fitting this model to annual and quarterly time-series data allows the authors to identify the channels through which macroeconomic innovations in one country impact on other countries in the union. Another finding is the extent of heterogeneity that exists across the member states in terms of the degree of similarity of macroeconomic transmission mechanisms, which is an important element in measuring the costs of union membership for each country.

Chapter 15 (Stéphane Dées) starts with the observation that the introduction of the euro has been associated with a persistent and steady divergence in external price competitiveness among the member states. Whereas some member states saw persistent gains in competitiveness, others registered substantial losses. At the same time, countries experienced a steady widening in current-account positions, with some countries accumulating very large deficits, which resulted in a sharp deterioration of their external net foreign asset positions. This is a cause of concern, as persistent losses in competitiveness and mounting external imbalances not only increase the economic and financial vulnerability of individual countries, but due to strong financial and trade interconnectedness of the euro area, they may also hinder the functioning of the European Monetary Union as a whole. This chapter discusses the response of external imbalances to some standardized economic shocks using a GVAR that includes wages, productivity, and external balance in addition to the usual macrovariables. Euro-area countries are modelled separately. The degree of improvement in competitiveness is assessed under three different shocks: a decrease in nominal wages, an increase in productivity, and a negative price mark-up shock. Overall, the results show that a decrease in wages leads to some short-term improvement in current account. At the same time to get significant effects, the wage shock would have to be relatively large. The productivity shock is less powerful on current account as the resulting improvement in GDP is likely to imply higher imports. Finally, the decrease in prices leads to some medium-term improvement in current account.

Chapter 16 (Katrin Assenmacher) assesses the forecast ability for Swiss output growth and inflation of a small GVAR model that includes Switzerland, the euro area, Japan, and the US. The author finds that the GVAR performs better than simple forecasting models. Imposing co-integrating restrictions improves forecasts, especially at longer horizons. While euro-area variables help forecast the Swiss economy, Japan and the US do not contain information for Swiss inflation. If the domestic economy is to be predicted, modelling the foreign economies explicitly is less important. It is also shown that during the recent financial crisis, non-model-based information results in improvements in forecasts at horizons of two-to-three quarters ahead.

Chapter 17 (Alessandro Galesi and Silvia Sgherri) presents a GVAR model that aims to assess the relevance of international spillovers, concentrating on the bank credit channel. To do so, the model is used to simulate the impact of a slowdown in US equity prices. The GVAR model contains 27 country-specific models, including the US, 17 European advanced economies, and nine European emerging economies. Each country model is linked to the others by a set of country-specific foreign variables, computed using bilateral bank lending exposures. Results reveal considerable co-movements of equity prices across mature financial markets. However, the effects on credit growth are found to be country-specific. Evidence indicates that asset prices are the main channel through which financial shocks in the short run are transmitted internationally, while the contribution of other variables, such as the cost and quantity of credit, becomes more important only over longer horizons.

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2

The basic GVAR DdPS model

*Filippo di Mauro and L. Vanessa Smith**

2.1 Introduction

A number of papers in the literature (e.g. Kose et al., 2003) argue that a rapidly rising degree of financial market integration has induced a closer financial and real international interdependence. Indeed, one of the most striking features of the business cycles across countries are the patterns of co-movement of output, inflation, interest rates, and real equity prices, which have become more pronounced over the past two decades. Any decisions made on the macroeconomic and risk management front should take into consideration these increasing interdependencies observed across markets and economies.

Higher interconnection across economies calls for adequate modelling. There are clearly many channels through which the international transmissions of business cycles can take place. In particular, they could be due to common observed global shocks (such as changes in oil prices), they could arise as a result of global unobserved factors (such as the diffusion of technological progress), or could be due to specific national or sectoral shocks. It is also likely that even when all 'common' factors are taken into account, there will be important residual interdependencies due to policy and trade spillover effects that remain to be explained. In fact, strong and increasing unilateral spillover effects from the North American area to the European area are being found, often interpreted as being caused by the process of globalization. Therefore, a fairly detailed global framework would be needed if we were to investigate the relative importance of such diverse sources of co-movements in the world economy.

This chapter presents a general, yet practical, global modelling framework for the quantitative analysis of the relative importance of different shocks

* We would like to thank Hashem Pesaran for useful discussions and suggestions in relation to this chapter.

and channels of transmission mechanisms, based on a global VAR (GVAR) model. The GVAR (Global Vector AutoRegressive) model combines individual country vector error-correcting models, in which domestic variables are related to country-specific foreign variables in a consistent manner. The latter are constructed from the domestic variables so as to match the international trade, financial or other desired pattern of the country under consideration, and serve as a proxy for common unobserved factors. This compact model of the world economy relies exclusively on observables, which typically include macroeconomic aggregates and financial variables. While the GVAR model is a suitable tool for policy analysis, its use is much broader, as will be shown by the breadth of applications covered in this handbook.

The version of the GVAR model that will be presented here is based on that of Dées, di Mauro, Pesaran, and Smith (2007, DdPS), which is estimated for 26 countries/regions, the euro area being treated as a single economy. The estimation sample extends that of DdPS by eight years, covering the period 1979–2011. This version also considerably extends the 11 country/region models estimated over the shorter period 1979–1999 in Pesaran, Schuermann, and Weiner (2004, PSW), where the GVAR model was initially introduced. Compared to PSW, this version of the model captures more fully the possible effects of bond markets, through the inclusion of the long-term as well as short-term interest rates.

The GVAR model allows for complex interactions/interdependencies at a variety of levels (national and international) in a transparent way, that can be empirically evaluated. It allows for long-run relationships consistent with the theory and short-run relationships that are consistent with the data. It handles the curse of dimensionality, by postulating that most of the foreign variables are weakly exogenous, an assumption shown to be supported by the data. The weak exogeneity assumption is the key feature of the GVAR modelling strategy, since it allows country models to be estimated individually and only at a later stage to be combined together. As long as this assumption holds, the GVAR methodology can be used with as many or as few countries as desired, while it can be equally applied to regions, states, or firms, to name a few possibilities. It is a very general modelling framework for any large system where components are driven by weighted averages of other components—whatever the data.

The rest of this chapter is organized as follows. Initially, the underlying mechanics of the GVAR methodology are presented. The use of the approach in modelling the international transmission of shocks is then demonstrated by employing the extended 1979–2011 GVAR data set, and following the GVAR model specification in DdPS. A selected number of results are presented for a set of eight focus countries, namely the US, the euro area, China, Japan, UK, Sweden, Switzerland, and Norway.[1]

2.2 Modelling international transmissions: a GVAR approach

2.2.1 *The country-specific VARX* models*

To motivate the GVAR model for the analysis of the international transmission mechanisms, suppose there are $N+1$ countries (or regions) in the global economy, indexed by $i = 0, 1, \ldots, N$, where country 0 serves as the numeraire country (which we take as the US, but could be any other country). The aim is to model a number of country-specific macroeconomic variables such as real GDP, inflation, interest rates, and exchange rates collected in the vector $\mathbf{x}_{it}$, over time, $t = 1, 2, \ldots, T$, and across the $N+1$ countries. Given the general nature of interdependencies that might exist in the world economy, it is clearly desirable that all the country-specific variables $\mathbf{x}_{it}$, $i = 0, 1, \ldots, N$, and observed global factors (such as oil prices) are treated endogenously. Attempting to do so, however, makes empirical estimation infeasible—what is generally known as the 'curse of dimensionality'. To face the issue, the GVAR framework imposes—and later tests empirically—weak exogeneity of the foreign country-specific and global variables, i.e. it assumes that the individual country (with the notable exception of the US) is actually a small economy with respect to the rest of the world.[2]

Each country includes a set of domestic, as well as foreign-specific variables, the number of which can vary across countries. Specifically, for country i, consider the VARX*(2,2) structure given by

$$\mathbf{x}_{it} = \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \mathbf{\Phi}_{i1}\mathbf{x}_{i,t-1} + \mathbf{\Phi}_{i2}\mathbf{x}_{i,t-2} + \mathbf{\Lambda}_{i0}\mathbf{x}^*_{it} + \mathbf{\Lambda}_{i1}\mathbf{x}^*_{i,t-1} + \mathbf{\Lambda}_{i2}\mathbf{x}^*_{i,t-2} + \mathbf{u}_{it}, \tag{2.1}$$

where $\mathbf{x}_{it}$ is a $k_i \times 1$ vector of domestic variables, $\mathbf{x}^*_{it}$ is a $k^*_i \times 1$ vector of foreign variables, and $\mathbf{u}_{it}$ is a serially uncorrelated and cross-sectionally weakly dependent process.[3] Foreign-specific variables are computed as weighted averages of the corresponding domestic variables of all countries, with the

[1] The GVAR modelling framework can be easily implemented using the GVAR Toolbox 2.0 developed by Smith and Galesi (2013). The toolbox operates on a flexible and user-friendly platform and is publicly available at: <https://sites.google.com/site/gvarmodelling/>, where the data and detailed results relating to the application in this chapter can be found.

[2] In other words, foreign variables are assumed to affect the domestic variables contemporaneously, and could be affected by lagged changes of domestic and foreign variables, but are not affected by long-run disequilibria in the domestic economy.

[3] Factor augmented vector autoregressions (FAVAR) could be viewed as an alternative approach to VARX* modelling of the individual countries, however, the number of estimated factors used in the former approach would be different for the different countries and it is not clear how these

weights also being country-specific; that is, $\mathbf{x}_{it}^* = \Sigma_{j=0}^{N} w_{ij}\mathbf{x}_{jt}$, where w_{ij}, $j = 0, 1, \ldots, N$, are a set of weights such that $w_{ii} = 0$ and $\sum_{j=0}^{N} w_{ij} = 1$. The weights are predetermined, and are meant to capture the importance of country *j* for the *i*th economy. They may reflect, for example, trade or financial linkages, depending on the purpose of the modelling exercise.

Estimation is performed by taking into account the integration properties of the series.[4] This allows us to distinguish between short-run and long-run relations and interpret the long-run relations as co-integrating. The error-correction form, VECMX*, of (2.1) can be written as

$$\Delta\mathbf{x}_{it} = \mathbf{c}_{i0} - \boldsymbol{\alpha}_i\boldsymbol{\beta}_i'[\mathbf{z}_{i,t-1} - \boldsymbol{\gamma}_i(t-1)] + \boldsymbol{\Lambda}_{i0}\Delta\mathbf{x}_{it}^* + \boldsymbol{\Gamma}_i\Delta\mathbf{z}_{i,t-1} + \mathbf{u}_{it}, \qquad (2.2)$$

where $\mathbf{z}_{it} = (\mathbf{x}_{it}', \mathbf{x}_{it}^{*\prime})'$, $\boldsymbol{\alpha}_i$ is a $k_i \times r_i$ matrix of rank r_i, and $\boldsymbol{\beta}_i$ is a $(k_i + k_i^*) \times r_i$ matrix of rank r_i. By partitioning $\boldsymbol{\beta}_i$ as $\boldsymbol{\beta}_i = (\boldsymbol{\beta}_{ix}', \boldsymbol{\beta}_{ix*}')'$ conformable to $\mathbf{z}_{it}$, the r_i error-correction terms defined by the above equation can be written as

$$\boldsymbol{\beta}_i'\left(\mathbf{z}_{it} - \boldsymbol{\gamma}_i t\right) = \boldsymbol{\beta}_{ix}'\mathbf{x}_{it} + \boldsymbol{\beta}_{ix*}'\mathbf{x}_{it}^* - \left(\boldsymbol{\beta}_i'\boldsymbol{\gamma}_i\right)t,$$

which allows for the possibility of co-integration both within $\mathbf{x}_{it}$ and between $\mathbf{x}_{it}$ and $\mathbf{x}_{it}^*$, and consequently across $\mathbf{x}_{it}$ and $\mathbf{x}_{jt}$ for $i \neq j$.[5]

The VECMX* models are estimated separately for each country conditional on $\mathbf{x}_{it}^*$, treating the $\mathbf{x}_{it}^*$ as 'long-run forcing' or $I(1)$ weakly exogenous with respect to the parameters of the conditional model (2.2). Estimation is based on reduced rank regression, taking into account the possibility of co-integration both within $\mathbf{x}_{it}$ and across $\mathbf{x}_{it}$ and $\mathbf{x}_{it}^*$. This way, the number of co-integrating relations, r_i, the speed of adjustment coefficients, $\boldsymbol{\alpha}_i$, and the cointegrating vectors, $\boldsymbol{\beta}_i$, for each country model are obtained.

The system can also be extended, as it is done in the application described in this chapter, to include common factors representing global variables, $\mathbf{d}_t$, such as oil prices. Weak exogeneity is also assumed for global variables.

2.2.2 *Solution strategy*

Although estimation is done on a country-by-country basis, the GVAR model is solved for the world as a whole (in terms of a $k \times 1$ global variable vector,

can be linked together in a global setting. See DdPS for the relation of the GVAR approach to the more common factor models used in the literature.

[4] The GVAR methodology can be applied to stationary and/or integrated variables.

[5] Even if the GVAR model is designed as an a-theoretical model, potentially it could integrate various economic relationships, such as the purchasing power parity (PPP) or the uncovered interest rate parity (UIP); see Dées, Holly, Pesaran, and Smith (2007). Further details concerning the estimation of the VARX* models can also be found in Garratt et al. (2006, Ch. 6).

$k = \sum_{i=0}^{N} k_i$), taking account of the fact that all the variables are endogenous to the system as a whole.

Starting from the country-specific VARX(2,2) models,

$$\mathbf{x}_{it} = \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \mathbf{\Phi}_{i1}\mathbf{x}_{i,t-1} + \mathbf{\Phi}_{i2}\mathbf{x}_{i,t-2} + \mathbf{\Lambda}_{i0}\mathbf{x}^*_{it} + \mathbf{\Lambda}_{i1}\mathbf{x}^*_{i,t-1} + \mathbf{\Lambda}_{i2}\mathbf{x}^*_{i,t-2} + \mathbf{u}_{it}, \tag{2.3}$$

define $\mathbf{z}_{it} = (\mathbf{x}'_{it}, \mathbf{x}^{*\prime}_{it})'$ and write (2.3) for each economy as

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

where

$$\mathbf{A}_{i0} = (\mathbf{I}_{k_i}, -\mathbf{\Lambda}_{i0}), \quad \mathbf{A}_{i1} = (\mathbf{\Phi}_{i1}, \mathbf{\Lambda}_{i1}), \quad \mathbf{A}_{i2} = (\mathbf{\Phi}_{i2}, \mathbf{\Lambda}_{i2}).$$

We can then use the link matrices $\mathbf{W}_i$ defined by the country-specific trade weights w_{ij} to obtain the identity

$$\mathbf{z}_{it} = \mathbf{W}_i\mathbf{x}_t, \tag{2.4}$$

where $\mathbf{x}_t = (\mathbf{x}'_{0t}, \mathbf{x}'_{1t}, \ldots, \mathbf{x}'_{Nt})'$ is the $k \times 1$ vector, which collects all the endogenous variables of the system, and $\mathbf{W}_i$ is a $(k_i + k^*_i) \times k$ matrix.

Using the identity given by (2.4) it follows that

$$\mathbf{A}_{i0}\mathbf{W}_i\mathbf{x}_t = \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \mathbf{A}_{i1}\mathbf{W}_i\mathbf{x}_{t-1} + \mathbf{A}_{i2}\mathbf{W}_i\mathbf{x}_{t-2} + \mathbf{u}_{it}, \quad \text{for } i = 0, 1, 2, \ldots, N,$$

and these individual models are then stacked to yield the model for $\mathbf{x}_t$ given by

$$\mathbf{G}_0\mathbf{x}_t = \mathbf{a}_0 + \mathbf{a}_1\mathrm{t} + \mathbf{G}_1\mathbf{x}_{t-1} + \mathbf{G}_2\mathbf{x}_{t-2} + \mathbf{u}_t, \tag{2.5}$$

where

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

$$\mathbf{a}_0 = \begin{pmatrix} \mathbf{a}_{00} \\ \mathbf{a}_{10} \\ \vdots \\ \mathbf{a}_{N0} \end{pmatrix}, \; \mathbf{a}_1 = \begin{pmatrix} \mathbf{a}_{01} \\ \mathbf{a}_{11} \\ \vdots \\ \mathbf{a}_{N1} \end{pmatrix}, \mathbf{u}_t = \begin{pmatrix} \mathbf{u}_{0t} \\ \mathbf{u}_{1t} \\ \vdots \\ \mathbf{u}_{Nt} \end{pmatrix}.$$

Since $\mathbf{G}_0$ is a known non-singular matrix that depends on the trade weights and parameter estimates, premultiplying (2.5) by $\mathbf{G}_0^{-1}$, the GVAR(2) model is obtained as

$$\mathbf{x}_t = \mathbf{b}_0 + \mathbf{b}_1 t + \mathbf{F}_1 \mathbf{x}_{t-1} + \mathbf{F}_2 \mathbf{x}_{t-2} + \boldsymbol{\varepsilon}_t, \tag{2.6}$$

where

$$\mathbf{F}_1 = \mathbf{G}_0^{-1}\mathbf{G}_1, \quad \mathbf{F}_2 = \mathbf{G}_0^{-1}\mathbf{G}_2,$$

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

Equation (2.6) can be solved recursively and used for a variety of purposes. There are no restrictions placed on the covariance matrix $\boldsymbol{\Sigma}_\varepsilon = \mathbf{E}(\boldsymbol{\varepsilon}_t \boldsymbol{\varepsilon}_t')$, unless one specifically decides to do so. For further details see PSW and DdPS.

As it is built, the GVAR model allows for interactions among the different economies through three distinct channels: (i) contemporaneous dependence of domestic variables, $\mathbf{x}_{it}$, on foreign-specific variables, $\mathbf{x}_{it}^*$, and on its lagged values; (ii) dependence of the domestic variables, $\mathbf{x}_{it}$, on common global (weakly) exogenous variables, $\mathbf{d}_t$ such as oil or food prices; (iii) contemporaneous dependence of shocks in country i on the shocks in country j, as described by the cross-country covariances.

2.3 The GVAR model (1979–2011)

The version of the GVAR model described in this chapter is an updated version of that presented in DdPS covering the period 1979q1–2011q2, and thus extending the sample used by DdPS by eight years.[6] The model includes 33 countries, where 8 of the 11 countries that originally joined the euro on 1 January 1999 are grouped together, and the remaining 25 countries are modelled individually (see Table 2.1). This GVAR, therefore, contains 26 countries/regions, covering about 90% of world output.

2.3.1 *Specification and estimation of the country-specific models*

The domestic and foreign variables included in the country-specific models are summarized in Table 2.2, where the variables are defined as

$$y_{it} = \ln\left(GDP_{it}/CPI_{it}\right), \ p_{it} = \ln(CPI_{it}), \ eq_{it} = \ln(EQ_{it}/CPI_{it}), \ e_{it} = \ln(E_{it}),$$

$$\rho_{it}^S = 0.25\ln(1 + R_{it}^S/100), \quad \rho_{it}^L = 0.25\ln(1 + R_{it}^L/100), \quad p_t^o = \ln(P_t^o),$$

where GDP_{it} = Nominal Gross Domestic Product of country i during period t, in domestic currency; CPI_{it} = Consumer Price Index in country i at time t;

[6] The extended GVAR data set (1979q1–2011q2) was prepared by Gang Zhang, Ambrogio Cesa Bianchi, and Alessandro Rebucci of the Inter-American Development Bank. This data set, together with a detailed description of the data sources and data extension, is publicly available at: <https://sites.google.com/site/gvarmodelling/data>.

Table 2.1. Countries and regions in the GVAR model.

US	**Euro area**	**Latin America**
China	Germany	Brazil
Japan	France	Mexico
UK	Italy	Argentina
	Spain	Chile
Other developed economies	Netherlands	Peru
Canada	Belgium	
Australia	Austria	
New Zealand	Finland	
Rest of Asia	**Rest of W. Europe**	**Rest of the world**
Korea	Sweden	India
Indonesia	Switzerland	South Africa
Thailand	Norway	Turkey
Philippines		Saudi Arabia
Malaysia		
Singapore		

Table 2.2. Domestic and foreign variables included in the country-specific models.

Variables	All countries excluding US		US	
	Endogenous	Foreign	Endogenous	Foreign
Real output	y_{it}	y^*_{it}	$y_{US,t}$	$y^*_{US,t}$
Inflation	Δp_{it}	Δp^*_{it}	$\Delta p_{US,t}$	$\Delta p^*_{US,t}$
Real exchange rate	$e_{it} - p_{it}$	–	–	$e^*_{US,t} - p^*_{US,t}$
Real equity price	eq_{it}	eq^*_{it}	$eq_{US,t}$	–
Short-term interest rate	ρ^S_{it}	ρ^{*S}_{it}	$\rho^S_{US,t}$	–
Long-term interest rate	ρ^L_{it}	ρ^{*L}_{it}	$\rho^L_{US,t}$	–
Oil price	–	p^o_t	p^o_t	–

EQ_{it} = Nominal Equity Price Index; E_{it} = Exchange rate of country i at time t in terms of US dollars; R^S_{it} = Nominal short-term rate of interest per annum, in percent; R^L_{it} = Nominal long-term rate of interest per annum, in percent; and P^o_t = Price of oil (in USD).

The country-specific foreign variables are constructed using trade weights. Trade weights can be fixed or time-varying. In the version presented here, the trade weights are based on the average trade flows computed over the three years 2006–08. The time-series data for the euro area are constructed by cross-section weighted averages of the domestic variables, over Germany, France, Italy, Spain, Netherlands, Belgium, Austria, and Finland, using the average Purchasing Power Parity GDP weights, also computed over the 2006–08 period.

While most countries include $y, \Delta p, e-p, eq, \rho^S$ and ρ^L as domestic variables, not all countries contain the same set due to insufficient data availability, and the fact that not all economies have well-developed capital markets. With the exception of the US model (see Table 2.2), all models include the country-specific foreign variables and the log of oil prices, as weakly exogenous in the sense discussed above. The US model contains $y, \Delta p, eq, \rho^S, \rho^L$, and oil prices, p^o, as the endogenous variables. The US dollar exchange rate is determined outside the US model. As in PSW, the only exchange rate included in the US model is the foreign real exchange rate variable $(e^* - p^*)$, which is treated as weakly exogenous. The inclusion of oil prices in the US model as endogenous, allows the evolution of the global macroeconomic variables to influence oil prices, a feature that was absent from the PSW version, which treated oil prices as weakly exogenous in all country-specific models. Furthermore, unlike the PSW version, the present specification includes US-specific foreign real output (y^*) and foreign inflation (Δp^*) as weakly exogenous variables. This allows for the US model to be more fully integrated in the world economy and hence to take a more satisfactory account of second-round effects in the global economic system as a whole. It is, of course, important that the weak exogeneity of these variables in the US model are tested, and this is done below.

Once the variables to be included in the different country models are specified, the integration properties of the domestic and foreign variables, as well as the global variable (oil price), are examined. Unit root tests, including standard Dickey–Fuller tests and weighted symmetric ADF type tests (Park and Fuller, 1995), at the 5% significance level, suggest that the majority of the variables are unable to reject the null of non-stationarity. The modelling exercise continues under the assumption that the country-specific foreign variables are weakly exogenous $I(1)$ variables, and that the parameters of the individual models are stable over time. Both assumptions are needed for an initial implementation of the GVAR model, and their validity will be examined in what follows.

The individual country models are formulated and estimated over the period 1979q2–2011q2. Next follows the choice of the lag orders of the individual country VARX* models, p_i and q_i, corresponding to the lag orders of the domestic and foreign variables, respectively. These are selected according to the Akaike information criterion, with $p_{\max_i}$ and $q_{\max_i}$ chosen to be no greater than 2. For the majority of countries, a VARX*(2,1) specification seemed to be satisfactory. The country-specific models in their vector error-correction form are then estimated based on reduced-rank regression. The rank of the co-integrating space is computed using the Johansen trace statistic as set out in Pesaran, Shin, and Smith (2000) for models with weakly exogenous $I(1)$ regressors (at the 95% critical value level). Specifically, two co-integrating relations are found for all focus countries, except Sweden and Switzerland for which three are found.[7] Serial correlation test results for the estimated country-specific residuals based on F-test statistics showed that serial correlation at the 5% significance level is rejected for the majority of equations.

2.3.2 *Testing for weak exogeneity*

As noted earlier, the main assumption underlying the estimation strategy is the weak exogeneity of $\mathbf{x}^*_{it}$ with respect to the long-run parameters of the conditional model. A formal test of this assumption for the country-specific foreign variables (the 'star' variables) and the oil prices can be carried out along the lines described by Johansen (1992) and Harbo et al. (1998). This involves a test of the joint significance of the estimated error-correction terms in auxiliary equations for the country-specific foreign variables, $\mathbf{x}^*_{it}$. In particular, for each ℓth element of $\mathbf{x}^*_{it}$ the following regression is carried out

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

where $ECM_{ij,t-1}$, $j = 1, 2, \ldots, r_i$, are the estimated error-correction terms corresponding to the r_i co-integrating relations found for the ith country model, and $\Delta \widetilde{\mathbf{x}}^*_{\text{it}} = (\Delta \mathbf{x}'^*_{it}, \Delta(e^*_{it} - p^*_{it}), \Delta p^o_t)'$. In the case of the US, the term $\Delta(e^*_{it} - p^*_{it})$ is implicitly included in $\Delta \mathbf{x}^*_{it}$. The test for weak exogeneity is an F-test of the joint hypothesis that $\delta_{ij,\ell} = 0$, $j = 1, 2, \ldots, r_i$, in the above regression. The test results for the focus countries are summarized in Table 2.3. The lag orders s_i and n_i were set to p_i and q_i, respectively; that is the lag orders of the corresponding country-specific VARX* models, though this need not necessarily be the case. Results at the 5% significance level show that the weak exogeneity assumption is rejected only for interest rates in the Japanese model. Based on the full set of results (not shown here), only in the case of 7 out of 146 regressions was the null hypothesis of weak exogeneity unable to be rejected. Aggregation of the euro area countries in a single model could have violated the weak exogeneity assumptions that underlie GVAR modelling. However, the tests suggest that the foreign euro area-specific variables can be considered as weakly exogenous. The same applies to the foreign variables (y^*_{US}, Δp^*_{US}, $e^*_{US} - p^*_{US}$) included in the US model.

[7] All country-specific VECMX* models were estimated including an unrestricted intercept and a trend restricted to lie in the co-integrating space.

Table 2.3. F-statistics for testing the weak exogeneity of the country-specific foreign variables and oil prices.

Country	F test	Foreign variables						
		y^*	Δp^*	eq^*	ρ^{*S}	ρ^{*L}	p^o	e^*-p^*
US	F(2,108)	1.12	2.72	–	–	–	–	1.89
Euro area	F(2,104)	1.62	2.29	0.16	2.14	1.17	0.76	–
China	F(2,112)	0.75	0.64	0.38	0.81	1.44	0.61	–
Japan	F(2,104)	0.92	0.25	0.17	3.17†	3.51†	1.64	–
UK	F(2,110)	2.44	1.41	0.27	0.87	0.75	1.71	–
Sweden	F(3,103)	0.48	0.58	0.11	1.18	0.60	0.47	–
Switzerland	F(3,109)	2.07	2.54	0.96	0.94	0.77	1.04	–
Norway	F(2,104)	1.63	1.06	1.70	0.16	1.38	0.56	–

Note: † denotes statistical significance at the 5% level.

2.3.3 *Testing for structural breaks*

The possibility of structural breaks is one of the fundamental problems facing econometric modelling, the likelihood of which increases, the longer the sample size. The GVAR model is not immune to this problem. Unfortunately, despite the great deal of recent research in this area, there is little known about how best to model breaks.

Table 2.4 reports a summary of several test statistics to assess the structural stability of the estimated coefficients[8] and error variances of the country-specific VECMX* models. The tests considered include: the maximal OLS cumulative sum (CUSUM) statistic, denoted by $PK_{\sup}$ and its mean square variant PK_{msq} (Ploberger and Krämer, 1992); a test for parameter constancy against non-stationary alternatives, denoted by $\mathfrak{N}$ (Nyblom, 1989); as well as sequential Wald type tests of a one-time structural change at an unknown change point specifically, the Wald form of the *QLR* statistic (Quandt, 1960), the *MW* statistic (Hansen, 1992), and the *APW* statistic (Andrews and Ploberger, 1994). See Supplement B of DdPS for a detailed presentation of these statistics. The heteroskedasticity-robust version of these tests is also presented.

Given the addition of eight years to the sample period used in DdPS, and thus the increased likelihood of structural breaks, it is reasonable to consider a 1% significance level for the implementation of these tests. The results vary across the tests, and to a lesser extent across the variables. For example, using the *PK* tests (both versions) the null hypothesis of parameter stability is rejected in at most 5 out of the possible maximum number of 134 cases, with the rejections confined to output, inflation, and the short-term interest

[8] Focus is on stability of the short-run coefficients. In fact, given the limited number of observations, tests for structural stability of long-run parameters may not be feasible.

Table 2.4. Number of rejections of the null of parameter constancy per variable across the country-specific models at the 1% level.

Alternative test statistics	Domestic variables						
	y	Δp	eq	ep	ρ^S	ρ^L	Numbers (%)
$PK_{\sup}$	2(7.7)	2(7.7)	0(0.0)	0(0.0)	1(4.0)	0(0.0)	5(3.7)
PK_{msq}	1(3.8)	1(3.8)	0(0.0)	0(0.0)	1(4.0)	0(0.0)	3(2.2)
$\mathfrak{N}$	0(0.0)	3(11.5)	3(15.8)	6(24.0)	2(8.0)	4(33.3)	18(13.4)
Robust-$\mathfrak{N}$	0(0.0)	0(0.0)	0(0.0)	1(4.0)	0(0.0)	1(8.3)	2(1.5)
QLR	4(15.4)	9(34.6)	7(36.8)	7(28.0)	12(48.0)	5(41.7)	44(32.8)
Robust-*QLR*	0(0.0)	2(7.7)	3(15.8)	0(0.0)	0(0.0)	3(25.0)	8(6.0)
MW	2(7.7)	3(11.5)	4(21.1)	8(32.0)	4(16.0)	4(33.3)	25(18.7)
Robust-*MW*	0(0.0)	1(3.8)	2(10.5)	2(8.0)	0(0.0)	3(25.0)	8(6.0)
APW	4(15.4)	8(30.8)	7(36.8)	8(32.0)	12(48.0)	6(50.0)	45(33.6)
Robust-*APW*	0(0.0)	3(11.5)	3(15.8)	0(0.0)	0(0.0)	2(16.7)	8(6.0)

Note: The test statistics $PK_{\sup}$ and PK_{msq} are based on the cumulative sums of OLS residuals, $\mathfrak{N}$ is the Nyblom test for time-varying parameters and *QLR*, *MW* and *APW* are the sequential Wald statistics for a single break at an unknown change point. Statistics with the prefix 'robust' denote the heteroskedasticity-robust version of the tests. All tests are implemented at the 1% significance level.

rate variable. Turning to the other four tests ($\mathfrak{N}$, *QLR*, *MW*, and *APW*), the outcomes very much depend on whether heteroskedasticity-robust versions of these tests are used. The results for the robust versions are in line with those of the *PK* tests, with the rate of rejections slightly higher, 2–6%, compared to the 2–4% obtained in the case of the *PK* tests. Once possible changes in error variances are allowed for, the parameter coefficients seem to have been reasonably stable. At least based on the available tests there is little statistical evidence with which to reject the hypothesis of coefficient stability in the case of 94% of the equations comprising the GVAR model. The non-robust versions of the $\mathfrak{N}$, *QLR*, *MW*, and *APW* tests, however, show a relatively large number of rejections, particularly *QLR* and *APW*, that lead to rejection of the joint null hypothesis (coefficient and error variance stability) in the case of 44 (*QLR*) and 45 (*APW*) out of the 134 cases. In view of the test outcomes for the robust versions of these tests, the main reason for the rejection seems to be breaks in error variances, and not the parameter coefficients. This conclusion is in line with many recent studies that find statistically significant evidence of changing volatility as documented, among others, by Stock and Watson (2002), Artis, Osborn, and Perez (2004), and Cecchetti, Flores-Lagunes, and Krause (2005).

Overall, not surprisingly there is evidence of structural instability, but this seems to be mainly confined to error variances. The problem of possibly changing error variances is dealt with by using robust standard errors when investigating the impact effects of the foreign variables, and the analysis of impulse responses is based on the bootstrap medians and confidence bounds, rather than the point estimates.

2.3.4 *Contemporaneous effects of foreign variables on their domestic counterparts*

Table 2.5 presents the contemporaneous effects of foreign variables on their domestic counterparts together with robust t-ratios computed using the Newey–West heteroskedasticity and autocorrelation consistent variance estimator. These estimates can be interpreted as impact elasticities between domestic and foreign variables. Most of these elasticities are significant and have a positive sign, as expected. They are particularly informative as regards the international linkages between the domestic and foreign variables. Taking, for instance, the euro area, a 1% change in foreign real output in a given quarter leads to an increase of 0.6% in euro area real output within the same quarter. Similar foreign output elasticities are obtained across the majority of focus countries.

We can also observe a high elasticity between long-term interest rates, ρ^L and ρ^{L*}, implying relatively strong co-movements between euro area and foreign bond markets. More importantly, the contemporaneous elasticity of real equity prices is significant and around one in most cases. Hence, the euro area stock markets would seem to overreact to foreign stock price changes, although the extent of overreaction is not very large. Similar results are also obtained for Sweden and Norway. Contemporaneous financial linkages are likely to be very strong amongst the European economies through the equity and the bond market channels.

Table 2.5. Contemporaneous effects of foreign variables on their domestic counterparts.

	Domestic variables				
Country	y	Δp	eq	ρ^S	ρ^L
US	0.61	0.10			
	[5.16]	[1.23]			
Euro area	0.60	0.23	1.04	0.05	0.68
	[5.92]	[3.24]	[20.34]	[2.96]	[8.56]
China	0.81	0.36		0.01	
	[3.66]	[1.49]		[0.48]	
Japan	0.79	−0.05	0.73	−0.02	0.48
	[3.02]	[−0.55]	[7.27]	[−0.59]	[5.99]
UK	0.90	0.77	0.84	0.15	0.74
	[6.45]	[4.99]	[13.39]	[1.82]	[7.97]
Sweden	1.31	1.15	1.16	0.31	0.90
	[4.49]	[6.87]	[19.86]	[2.22]	[6.48]
Switzerland	0.61	0.44	0.92	0.19	0.46
	[6.52]	[4.14]	[15.42]	[3.61]	[8.27]
Norway	0.19	0.93	1.08	0.14	0.72
	[0.98]	[3.70]	[9.76]	[0.83]	[5.15]

Note: Newey–West robust to autocorrelation and heteroskedasticity t-ratios are given in square brackets.

In contrast, we find rather low elasticities for inflation. For the euro area the foreign inflation elasticity is 0.23, suggesting that in the short run the euro area prices are not much affected by changes in foreign prices. The same is also true for the US. For the remaining focus countries, with the exception of Japan, foreign inflation effects are much larger and are statistically significant.

Another interesting feature of the results are the very weak linkages that seem to exist across short-term interest rates (Sweden being an exception) and the high, significant relationships across long-term rates. This clearly shows a much stronger relation between bond markets than between monetary policy reactions.

2.3.5 *Average pairwise cross-section correlations*

One of the key assumptions of the GVAR modelling approach is that the 'idiosyncratic' shocks of the individual country models should be cross-sectionally 'weakly correlated', so that $Cov(\mathbf{x}_{it}^{*}, \boldsymbol{u}_{it}) \rightarrow 0$, with $N \rightarrow \infty$, and as a result the weak exogeneity of the foreign variables is ensured. As a simple diagnostic of the extent to which the country-specific foreign variables have been effective in reducing the cross-section correlation of the variables in the GVAR model, average pairwise cross-section correlations are computed for the first differences of the endogenous variables of the model, and for the associated residuals of the country-specific VECMX* models over the estimation period, 1979–2011. The results for all variables are summarized in Table 2.6.

Real equity prices show the highest cross-section correlation among the variables in first differences ranging between 44% and 56%; they are followed by long-term interest rates (28–46%), real exchange rates, which are in the 30% range for the majority of countries, and finally output, inflation, and short-term interest rates. Overall, there is significant evidence of cross-country correlations for the variables in the GVAR model, even when transformed to stationarity by first differencing (results for the levels of the variables not shown here are much higher).

Turning to the cross-section correlation of the residuals from the VECMX* models (including domestic and foreign star variables), it is quite striking that except for real exchange rates these correlations are very small and do not depend on the choice of the variable or country. This is particularly apparent in the case of the equity and bond markets, where the cross-section correlation of the residuals ranges between –11% and +7%. The model has clearly been successful in capturing the common effects driving bond and equity markets. The real exchange rate variable presents an important exception, which requires further consideration.

Table 2.6. Average pairwise cross-section correlations of all variables and VECMX* residuals.

Country	First differences of domestic variables					
	y	Δp	eq	$e\text{-}p$	ρ^S	ρ^L
US	0.24	0.19	0.53	–	0.11	0.40
Euro area	0.26	0.17	0.56	0.36	0.18	0.46
China	0.08	0.07	–	0.09	0.07	–
Japan	0.16	0.10	0.44	0.17	0.05	0.28
UK	0.20	0.11	0.55	0.34	0.16	0.39
Sweden	0.20	0.11	0.50	0.35	0.10	0.38
Switzerland	0.21	0.11	0.53	0.31	0.09	0.38
Norway	0.11	0.09	0.49	0.39	0.05	0.31

Country	VECMX* residuals					
	y	Δp	eq	$e\text{-}p$	ρ^S	ρ^L
US	−0.05	0.04	−0.02	–	0.04	−0.02
Euro area	−0.05	0.03	−0.11	0.31	0.05	−0.07
China	−0.07	−0.02	–	0.05	0.01	–
Japan	−0.05	0.04	−0.11	0.14	0.01	−0.05
UK	0.00	0.00	−0.02	0.24	0.03	−0.02
Sweden	0.02	0.03	−0.03	0.24	0.01	0.02
Switzerland	0.01	0.05	0.01	0.29	0.00	0.02
Norway	−0.01	0.02	0.07	0.30	0.02	0.01

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

2.4 Generalized impulse response functions

To study the dynamic properties of the global model and to assess the time profile of the effects of variable-specific shocks across economies, the implications of two different external shocks (of a size of one standard error) are presented: (i) a negative shock to US real equity prices; and (ii) a positive shock to US GDP. The generalized impulse response function (GIRF) is employed for this purpose, proposed by Koop et al. (1996) and further developed by Pesaran and Shin (1998) for vector error-correcting models.

The GIRF is an alternative to the orthogonalized impulse responses (OIR) of Sims (1980). The OIR approach requires the impulse responses to be computed with respect to a set of orthogonalized shocks, while the GIRF approach considers shocks to individual errors and integrates out the effects of the other shocks using the observed distribution of all the shocks without any orthogonalization. Unlike the OIR, the GIRF is invariant to the ordering of the variables and the countries in the GVAR model, which is clearly an important consideration. The GIRF provides useful information with respect to changes in the underlying variables. Although the GIRF approach cannot provide information on the reasons behind the changes, it can be quite informative about the dynamics of the transmission of shocks.

Consider the solution of the GVAR model given by (2.5). The GIRFs are based on the definition

$$GIRF(\mathbf{x}_t; u_{i\ell t}, n) = E(\mathbf{x}_{t+n}|u_{i\ell t} = \sqrt{\sigma_{ii,\ell\ell}}, I_{t-1}) - E(\mathbf{x}_{t+n}|I_{t-1}),$$

where I_{t-1} is the information set at time $t-1$, $\sigma_{ii,\ell\ell}$ is the diagonal element of the variance–covariance matrix $\mathbf{\Sigma}_u$ corresponding to the ℓth equation in the ith country, and n is the horizon. It follows that the GIRFs of a unit (one standard error) shock at time t to the ℓth equation in the above model on the jth variable at time $t+n$ is given by the jth element of

$$GIRF(\mathbf{x}_t; u_{i\ell t}, n) = \frac{\mathfrak{e}_j' \mathbf{A}_n \mathbf{G}_0^{-1} \mathbf{\Sigma}_u \mathfrak{e}_\ell}{\sqrt{\mathfrak{e}_\ell' \mathbf{\Sigma}_u \mathfrak{e}_\ell}}, \; n = 0, 1, 2, \ldots; \ell, j = 1, 2, \ldots, k, \tag{2.7}$$

where $\mathfrak{e}_\ell = (0, 0, \ldots, 0, 1, 0, \ldots, 0)'$ is a selection vector with unity as the ℓth element in the case of a country-specific shock.[9] Though not presented here, global and regional shocks can also be entertained. For, say, a global equity shock, $\mathfrak{e}_\ell$ has PPP GDP weights that sum to one, corresponding to the equity shocks of each of the $N+1$ countries and zeros elsewhere. For a regional equity shock, $\mathfrak{e}_\ell$ has PPP GDP weights that sum to one corresponding to the equity shocks of each of the countries that belong to the selected region, and zeros elsewhere.

The figures presented below give bootstrap estimates of the GIRFs and their associated 90% confidence bounds.[10] The figures show that the GIRFs settle down reasonably quickly, suggesting that the model is stable. This is supported by the eigenvalues of the GVAR model, which are 268 in total.[11] From the individual country models and the theorem in PSW the rank of the co-integrating matrix in the global model is not expected to exceed 55

[9] The $\mathbf{A}_n$ matrices are calculated recursively as $\mathbf{A}_n = \mathbf{F}_1 \mathbf{A}_{n-1} + \mathbf{F}_2 \mathbf{A}_{n-2} + \ldots + \mathbf{F}_p \mathbf{A}_{n-p}$, $n = 1, 2, \ldots$, with $\mathbf{A}_0 = \mathbf{I}_m$, $\mathbf{A}_n = \mathbf{0}$, for $n < 0$.

[10] All GIRFs were computed setting the shrinkage parameter for the covariance matrix, Σ_u, equal to 0.8. The computation of the bootstrap bounds is based on the sieve bootstrap procedure discussed in the appendix of the GVAR Toolbox 2.0 user guide.

[11] The GVAR contains 134 endogenous variables with a maximum lag order of 2, which gives rise to a companion VAR(1) model in 268 variables.

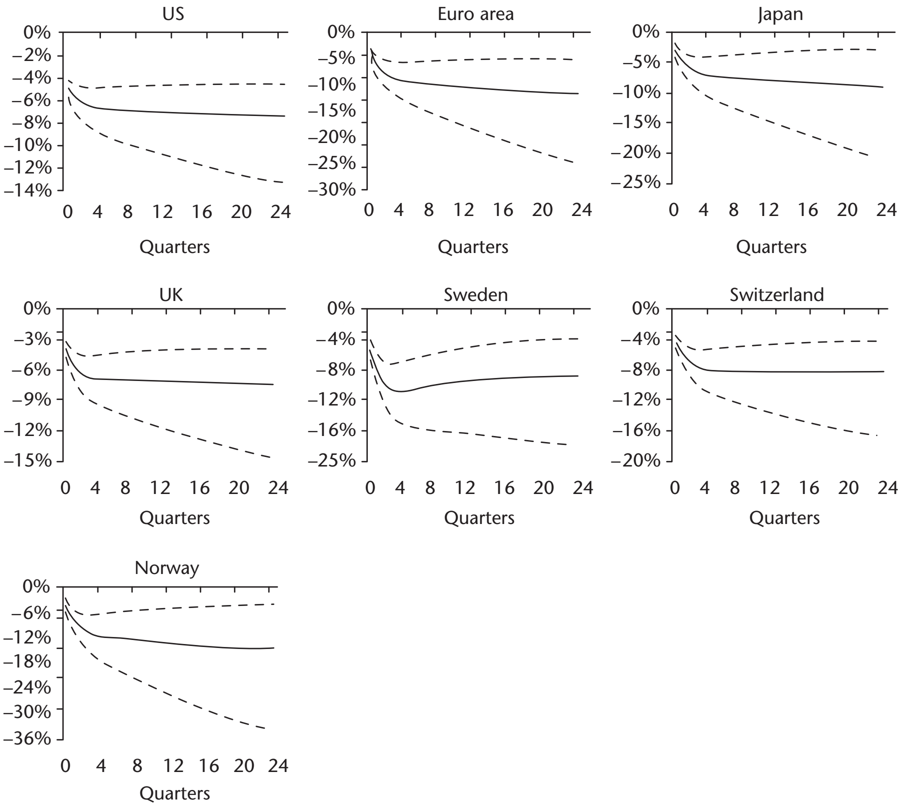

Figure 2.1. Generalized impulse responses of a one-standard-error shock (−) to US real equity prices on real equity prices across countries (bootstrap median estimates with 90% bootstrap error bounds).

(namely the number of co-integrating relations in all the individual country models). Hence, the global system should have at least 79 eigenvalues (i.e. 134–55), that fall on the unit circle. The GVAR satisfies these properties and indeed has 79 eigenvalues equal to unity, with the remaining 189 eigenvalues having moduli all less than unity.[12]

2.4.1 *Shock to US equity prices*

Consider first the GIRFs for a one standard error negative shock to US equity prices on equity prices across countries, given by Figure 2.1. This shock is

[12] Of these 189 eigenvalues, 108 (54 pairs) are complex, introducing cyclical features in the impulse responses. The eigenvalues with the largest complex part are $-0.513085 \pm 0.65477i$, $0.185191 \pm 0.587136i$, and $0.202823 \pm 0.5456i$, where $i = \sqrt{-1}$. After the unit roots, the three largest eigenvalues (in moduli) are 0.888084, 0.86509, and 0.840866, implying a reasonable rate of convergence of the model after a shock to its long-run equilibrium. Given the unit eigenvalues of the system, some shocks will have permanent effects on the levels of the endogenous variables.

equivalent to a fall of around 6–7% in US real equity prices per quarter. The transmission of the shock to the rest of the countries takes place rather quickly and the effects of the shock are statistically significant. On impact, equity prices fall by 5% in the US, 3% in Japan, and around 4–5% in the other countries. The effects of the US shock on all countries (especially the euro area and Norway) become more pronounced over the first two years, suggesting a mild overreaction of equity prices in the European markets to the US shock. This partly reflects the higher volatility of the European equity markets as compared to the volatility of the S&P 500 used as the market index for the US.

The equity price shock is accompanied by a decline in US real GDP of around 0.08% on impact, by 0.9% on average over the first year, and by 1.2% on average over the second year (see Figure 2.2). Like in the US, real output in all countries is negatively affected by the adverse equity shock,

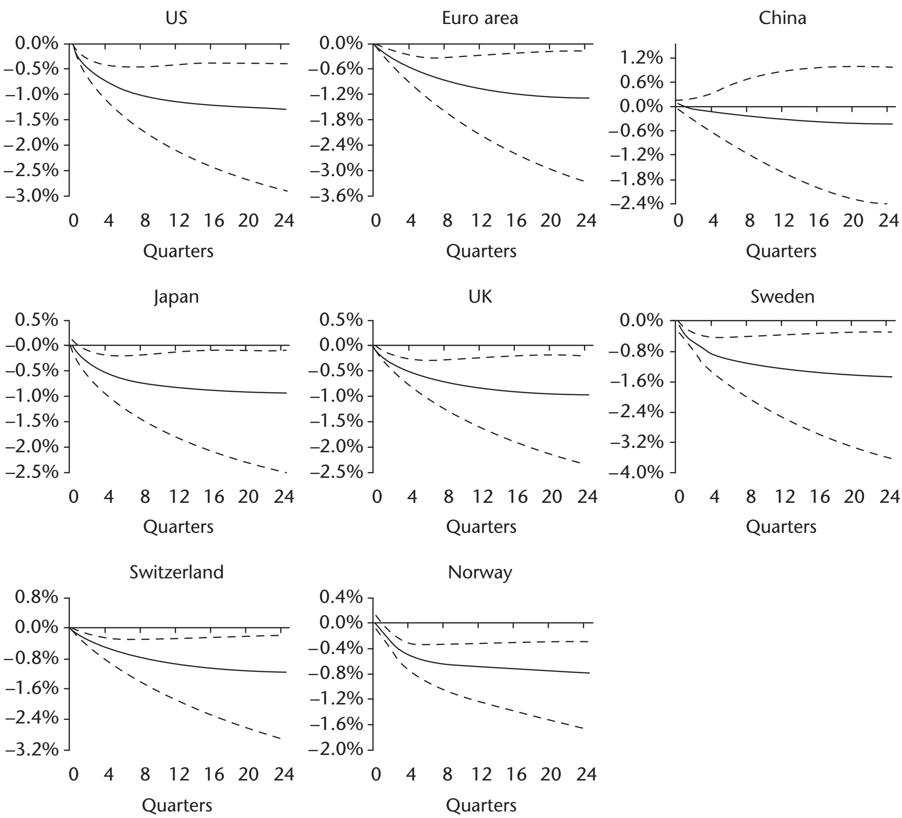

Figure 2.2. Generalized impulse responses of a one-standard-error shock (–) to US real equity prices on real output across countries (bootstrap median estimates with 90% bootstrap error bounds).

although to a lesser extent, with the exception of Sweden, which exhibits a more pronounced effect. All responses are statistically significant except for China. Contrary to the other countries that exhibit highly correlated and integrated equity markets, China does not have an equity market and therefore does not benefit from changes in the rest of the world.

2.4.2 *Shock to US GDP*

Figures 2.3 and 2.4 report the GIRFs related to a positive shock to US GDP. The change in US activity has a significant and positive affect on real output on all countries, with the exception of China. The responses are typically significant over the first eight quarters, ranging from 0.2% to 0.5% on average over the first year, compared to 0.7% for the US. The strongest impact is on

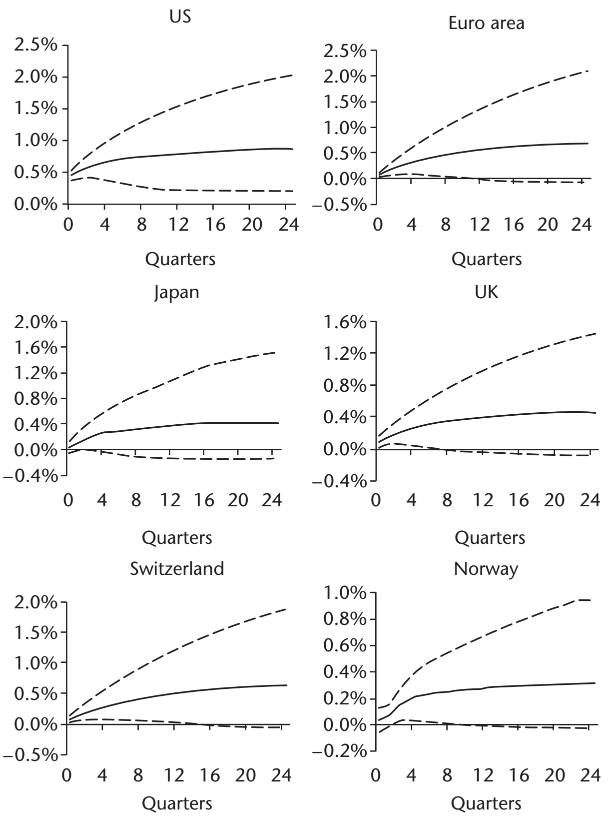

Figure 2.3. Generalized impulse responses of a one-standard-error shock (+) to US real output on real output across countries (bootstrap median estimates with 90% bootstrap error bounds).

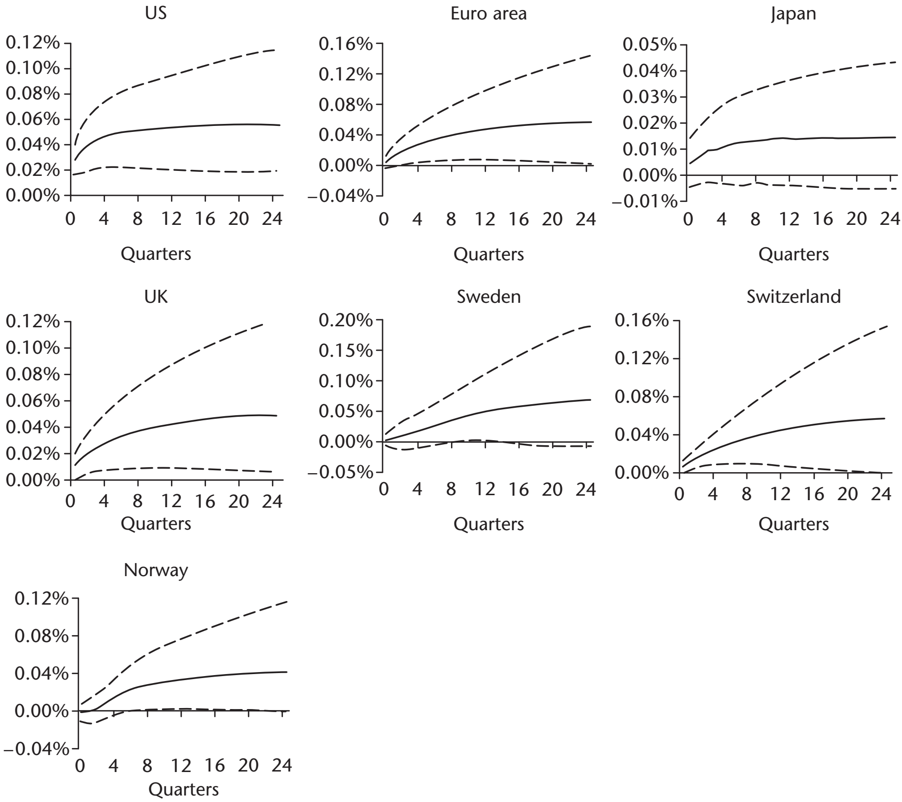

Figure 2.4. Generalized impulse responses of a one-standard-error shock (+) to US real output on long-term interest rates across countries (bootstrap median estimates with 90% bootstrap error bounds).

the euro area and Sweden. The real shock appears to transmit much more slowly than the financial shock had (Figure 2.3).

The impact on long-term interest rates suggests that the model captures and quantifies effectively the steepening of the US yield curve in response to an expansion of US real output (Figure 2.4). The responses of all countries are positive and significant, with the exception of Japan, while for Sweden and Norway significant responses are observed after the first 5–6 quarters. The responses are 0.02–0.03% over the first year and 0.05% for the US.

2.5 Conclusions

This chapter provided a brief overview of the GVAR modelling framework and presented the basic DdPS GVAR model, which lies at the heart of a number of the ensuing chapters. The DdPS GVAR model was then applied to an extended data set (1979–2011) covering the recent crises.

Although the GVAR model can be used for many different purposes, in this chapter, the emphasis has been on its short-term and long-term implications of external shocks for a set of focus economies. Impact effects of external changes in interest rates (short-term and long-term rates), inflation, output, real equity prices, real exchange rates, and oil prices are provided, and the time profiles of these shocks are presented using generalized impulse response functions.

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

The results suggest that financial shocks are transmitted relatively rapidly, and often get amplified as they travel from the US to the rest of the world. Equity and bond markets seem to be far more synchronous as compared to real output, inflation, and short-term interest rates.

The model also highlights the importance of second-round effects of the shocks. A shock in the US can be amplified because the US will also be affected over time through the return impacts of output and inflation shocks in the rest of the world. The rest of the countries in turn react to the US shocks directly, as well as indirectly through the impact of the US shocks on their trade partners, and so on. The transmission of shocks does not take place only through trade, but also as importantly through the impacts on financial variables, with subsequent spillover effects on real variables. The GVAR presents a complicated, yet simple-to-follow, spatio-temporal structure for the analysis of the world economy. To be sure, and it is shown in this handbook, it can be rather easily modified and extended further for the analysis of global interdependencies.

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Part I

International transmission and forecasting

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3

Global recessions and output interdependencies in a GVAR model of actual and expected output in the G7

Anthony Garratt, Kevin Lee, and Kalvinder Shields

3.1 Introduction

It is well understood that the performance of the world's economies is closely tied through trade and international capital markets and that technology-led growth and business cycle fluctuations in one country are, at some point and in one way or another, typically transmitted to others. The idea is described clearly in a recent IMF (2009) study of periods of recession and recovery in 21 advanced economies during the past 50 years. The study presents summary statistics to show that recessions in different countries have been considerably deeper when they are synchronized across countries compared to those that are more localized. The synchronized recessions have also lasted longer, with investment and asset prices continuing to decline following output troughs in the separate countries, credit growth remaining weak, and export growth remaining sluggish in the face of weak external demand.

There is no shortage of papers in the academic literature concerned with investigating the nature of these cross-country interactions in the global business cycle through more formal modelling. As discussed in Chapter 1, there is considerable diversity in the modelling approaches found in the literature, ranging from very detailed structural economic models to relatively narrow statistical characterizations. The multi-country models discussed in Chapter 2 illustrate an intermediate approach to striking the appropriate balance between the use of theory and evidence. These construct 'starred' variables to capture the effect of external influences and use these to define economically meaningful long-run relations between a small number of macroeconomic aggregates, which are incorporated into separate national VAR models following the 'long-run structural modelling strategy' described in Garratt et al. (2006). The national models are then brought together in a single coherent GVAR system.

The modelling of this chapter is in the same vein as these recent papers estimating separate-country models using starred variables and organizing these into a GVAR to capture cross-country interactions. But the approach is more parsimonious in its use of data by focusing on actual output data and direct measures of expected output obtained from surveys. In principle, the expectations data summarize the effects of *all* the potential influences on output, as perceived by those forming the expectations. The data therefore have the same informational advantages that the dynamic factor models have compared to more structural models (which limit attention to the variables involved in the key—although still potentially contentious—behavioural relations). But the variable retains a straightforward economic interpretation and can be used to address meaningful economic questions relating to—for example—national and global recessionary events.

The use of the GVAR system has the additional advantage that, despite its ability to capture complicated international linkages, it retains a simple VAR structure, which is handy in simulations. Simulation exercises are very convenient, for example, if interest is on not just point forecasts but also density forecasts, event probability forecasts, and decision-making using the model. Starting from the available data at time t, artificial future time paths for the series can be simulated using the model estimated on the time-t data (including the time-t characterization of the variance–covariance matrix that describes the correlations of shocks to the various variables). These simulated futures trace out the entire density of forecast outcomes, with the average value over the simulated futures providing the point forecast of the series. Further, by simply counting the number of times that a specified event takes place in the simulated futures, we also obtain a forecast of the probability that the event will occur. And, if a decision-making context is sufficiently well-defined (with a clear link between actions and outcomes and an objective function defined over outcomes), the model's forecasts can be used to evaluate the likely consequences of actions so as to make the best decisions. All of these exercises are computationally very straightforward within the GVAR modelling framework.[1]

The empirical work of the chapter focuses on output in the G7 economies over the period 1994q1–2011q2. The estimated model can be used to inves-

[1] See Garratt et al. (2003) for further discussion of the use of simulations in generating event probability forecasts; and Garratt and Lee (2010) for a discussion of their use in the context of decision-making over portfolio composition.

tigate a range of recessionary events over the second half of the sample to highlight the different features of the global recession experienced since 2008. In this chapter, however, we focus on a very short-term horizon event, using the model to assess whether the G7 economies are in recession in each quarter as it would have been judged in real time and taking into account the delays that exist in the publication of official output data. The fact that the event of interest has such a very short (indeed contemporaneous) time-frame provides an unusual and particularly challenging forecasting context. As it turns out, however, we find that the expectations data and the foreign outputs data make complementary contributions to capturing the interdependencies of the national output data. This means both elements of the model are important in characterizing the international output data movements and in obtaining good forecasting performance for different types of recessionary events.

3.2 Modelling output in a global economy

3.2.1 *Parsimony and the use of survey data*

It is not straightforward to describe accurately the dynamics of output because of the complex interactions and feedbacks that exist between output and other macroeconomic variables. However, the difficulties of examining macrodynamics are easily sidestepped if we use survey data that measure agents' expectations of output alongside the actual output because the survey data convey information about the macrosystem in a very parsimonious way.

The advantages of using direct measures of expectations in macromodelling arise from various sources. First, the use of survey measures means that structural macrorelationships that involve expectations can be considered directly and explicitly. In the absence of survey data, additional assumptions on the nature of the expectation formation process are required and it is difficult to disentangle the separate contributions to the system dynamics made by the structural model from those arising from the assumed expectations formation process. Second, the survey data provides a good summary of all the influences on a variable without requiring the full detail of the (potentially very large and complicated) structural model. Indeed, if expectations are formed rationally and if the survey captures the true expectations accurately, the survey data capture *all* of the influences on the variable of interest as dated at the time of the survey and is therefore *the most effective* way of capturing the multitude of influences on the variable exerted in reality. Third, and related, the survey data might contain important information on the nature of learning or of imitative or herding behaviour, say, that has a significant impact on macrodynamics in its own right and that can only be captured by the survey data. And fourth, as elaborated in Garratt et al. (2012), a VAR model involving survey measures of expectations for up to h quarters, say, can replicate the dynamics of a structural VAR model involving h macrovariables exactly (so that, for example, a VAR model of actual and two expectations of output could match the dynamics of a typical three-equation new Keynesian macromodel, say). Moreover, the model using the survey data would be consistent with any structural model of the same size so is robust to the modelling assumptions underlying the structural models and, in some circumstances, is less sensitive to structural breaks. In short, survey data are able to summarize past macroeconomic dynamics in a parsimonious way and provide an extremely useful tool in any time-series modelling exercise aiming to explain output dynamics and to characterize business cycles and recession.

3.2.2 *Recessions and decision-making in real time*

It seems likely that the attention paid to business cycles and recessions, in the media and in the academic literature, arises because these events impact on individuals' decision-making. This might also explain why the concept of a 'recession' is so difficult to define precisely.[2] Some agents' view of recession relates to the consequences of a downturn (captured by negative growth, say) experienced today, while others consider recession to be a longer-term concept (relating to the output relative to a recent peak level, say, or relative to a trend defined over a long time horizon). Seen from this perspective, recession is a multi-faceted concept and one that is best described not through a single NBER-type statement but through discussion of a range of recessionary events that will capture the business-cycle features relevant to different decision-makers. This idea is elaborated and explored in Lee and Shields (2011).

The focus on the decision-making dimension of recessionary events emphasizes the need to consider models and forecasts made in real time; one needs to understand the context in which decisions are made to properly understand why the outcomes are as they are. This provides another justification for the use of direct measures of expectations, since these provide a very explicit statement on people's subjective views on the current state of the economy as formed in real time. It also focuses attention on 'nowcasts' of today's output prospects. This is because output data is published only

[2] See, for example, Harding and Pagan's (2005) discussion and the special issue of the *Journal of Applied Econometrics* in which it was published.

with a lag of, typically, one quarter so that agents are always unsure of the current state of the economy.[3]

In what follows, we denote (the logarithm of) output at time t by y_t and the measure of y_t published in time $t+s$ by ${}_{t+s}y_t$. If $s \geqslant 1$, the measure is from an official publication (published after the one-quarter publication delay). If $s \leqslant 0$, the measure is a direct measure of expectations on y_t as published in $t+s$ (and the point is emphasized by a superscript 'e'). A modelling framework that can accommodate the publication delays and the role of surveys on contemporaneous and future outputs is given by

$$\begin{bmatrix} {}_ty_{t-1} - {}_{t-1}y_{t-2} \\ {}_ty_t^e - {}_ty_{t-1} \\ {}_ty_{t+1}^e - {}_ty_t^e \end{bmatrix} = \Gamma_0 + \sum_{i=1}^{p} \Gamma_i \begin{bmatrix} {}_{t-i}y_{t-1-i} - {}_{t-1-i}y_{t-2-i} \\ {}_{t-i}y_{t-i}^e - {}_{t-i}y_{t-1-i} \\ {}_{t-i}y_{t+1-i}^e - {}_{t-i}y_{t-i}^e \end{bmatrix} + \begin{bmatrix} \varepsilon_{bt} \\ \varepsilon_{ct} \\ \varepsilon_{ft} \end{bmatrix} \tag{3.1}$$

for $t = 1, \ldots, T$, where the Γ are matrices of parameters and the ε are mean-zero innovations with variance–covariance matrix Ω and where, for ease of exposition, we focus here on the case where only contemporaneous and one-period-ahead forecasts are used. This model explains the growth in actual output at time $t-1$ (published in time t following the one-quarter publication delay), the expected contemporaneous growth in output (published as a nowcast in the survey dated at time t), and the expected one-period ahead growth in output (also published in the survey dated at time t). The model assumes that actual output growth is stationary and that expectational errors are stationary but is quite general otherwise.

The model is best estimated in the form in (3.1), but it can be written in levels form as

$$\mathbf{z}_t = \mathbf{A}_0 + \sum_{s=1}^{p+1} \mathbf{A}_s \mathbf{z}_{t-s} + \boldsymbol{\varepsilon}_t, \qquad t = 1, \ldots, T, \tag{3.2}$$

where $\mathbf{z}_t = ({}_ty_{t-1},\ {}_ty_t^e,\ {}_ty_{t+1}^e)'$, $\boldsymbol{\varepsilon}_t = (\varepsilon_{bt},\ \varepsilon_{ct},\ \varepsilon_{ft})'$ and the $\mathbf{A}$'s are functions of the original Γ's.[4] Its simple linear form makes (3.2) particularly suitable for forecasting and decision-making using simulation methods. Random draws from the estimated variance–covariance matrix Ω can be used to simulate future paths for the $\mathbf{z}_t$'s ($t = T+1, \ldots, T+h$), taking the estimated $\mathbf{A}$'s as being true and known. This generates the entire forecast density $\Pr(\mathbf{Z}_{T+1,T+h} \mid \mathbf{Z}_{1,T})$ showing the likelihood of observing $\mathbf{Z}_{T+1,T+h} = \{\mathbf{z}_T,\ \mathbf{z}_{T+1}, \ldots, \mathbf{z}_{T+h}\}$

[3] The first-release data is also often revised, introducing a further complexity in decision-making. As we explain below, in what follows, we ignore the revisions process, effectively assuming that subsequent revisions simply constitute noise. See Mankiw and Shapiro (1986) and Garratt et al. (2008) for more discussion of the analysis of revisions data.

[4] The model can also be written as a co-integrating VAR in the difference of $\mathbf{z}_t$, in which the assumed stationarity of the expectational errors is reflected in (two) co-integrating vectors that ensure the three output measures move together one-for-one in the long run.

given the observed data $\mathbf{Z}_{1,T} = \{\mathbf{z}_1, \mathbf{z}_2, \ldots, \mathbf{z}_T\}$ and taking into account the stochastic uncertainty surrounding the model. Alternatively, the estimated model can be used to generate artificial histories (using actual data for $t = 1, \ldots, p+2$ and simulating data for $t = p+3, \ldots, T$), each of which can be used to estimate an alternative version of (3.2) and to generate simulated future paths. The resultant density obtained across all simulated futures takes into account both the stochastic uncertainty and parameter uncertainty associated with the model. (See Garratt et al., 2003, 2008 for further detail and discussion.)

Perhaps even more importantly, the models can also be used to produce forecasts of the probability of specific events taking place and to make decisions that depend on the events. This means the framework is very suitable for examining the likelihood of recession however it is defined. Specifically, any recessionary event defined as a set of outcomes involving current and future actual outputs, ${}_{T+1}y_T, {}_{T+2}y_{T+1}, {}_{T+3}y_{T+2}, \ldots$ can be written as $R(\mathbf{Z}_{T+1,T+h})$ so that the probability that the event occurs is

$$\text{probability of recession} = \int_R \Pr(\mathbf{Z}_{T+1,T+h} | \ \mathbf{Z}_{1,T}) \ \ \partial \mathbf{Z}_{T+1,T+h}. \tag{3.3}$$

In the simulation exercise, this is shown simply by the proportion of the simulations in which the event occurred. Equally, in a decision-making context, where an individual's objective function $v(\omega, R(\mathbf{Z}_{T+1,T+h}))$ depends on the outcome of a choice variable ω and the occurrence of the recessionary event, the decision-maker's problem can be written as

$$\max_{\omega} \left\{ \int v(\omega, R(\mathbf{Z}_{T+1,T+h})) \Pr\left(\mathbf{Z}_{T+1,H} \mid \mathbf{Z}_T\right) \ \ d\mathbf{Z}_{T+1,T+h} \right\}. \tag{3.4}$$

In terms of the simulations, the decision involves evaluating the objective function for different values of ω in each simulation and simply choosing the value of ω that, averaging across the simulations, maximizes the value of the objective function.

The expressions in (3.3) and (3.4) emphasize the idea that the concept of a recession is often important only in so far as it is helpful in making decisions and is likely to differ from individual to individual. In the absence of an explicitly defined objective function, it is not possible to provide a definitive statement on recession, therefore. But the discussion suggests that it will be helpful to convey the range of potential future output outcomes by providing probability forecasts for a small number of alternative recessionary events rather than focusing on point forecasts for output or a particular definition of recession.

3.2.3 *Global interactions*

The final layer of complexity arising in a model explaining global output movements arises because of the potential effects of common factors that drive output in many countries simultaneously. These could be justified through common demand or productivity shocks, for example, or through the self-reinforcing outcomes of bouts of global pessimism or optimism, which drive changes in risk premia across all countries.[5] Using an i subscript to denote country i, the model in (3.2) can accommodate the presence of unobserved global factors $\mathbf{f}_t$ by writing

$$\mathbf{z}_{it} = \mathbf{A}_{i0} + \sum_{s=1}^{p+1} \mathbf{A}_{is}\mathbf{z}_{i,t-s} + \mathbf{A}_{if}\mathbf{f}_t + \boldsymbol{\varepsilon}_{it}, \qquad i = 1, \ldots, n \quad \text{and} \quad t = 1, \ldots, T, \quad (3.5)$$

where $\boldsymbol{\varepsilon}_{it}$ now represent country-specific innovations. Assuming this relationship holds for all countries $i = 1, \ldots, n$, Chapter 2 of this book notes that we can construct global variables $\mathbf{z}_t^* = \sum_{i=1}^n w_i \mathbf{z}_{it}$ using fixed weights w_i and that, under reasonable assumptions, an aggregate relationship explaining $\mathbf{z}_t^*$ can be derived of the same form as (3.5). In this case, the unobservable common factor can be reasonably proxied by the observable vector $(1, \mathbf{z}_t^{*\prime}, \mathbf{z}_{t-1}^{*\prime}, \ldots, \mathbf{z}_{t-p+1}^{*\prime})'$ and the national model in (3.2) can be written

$$\mathbf{z}_{it} = \mathbf{B}_{i0} + \sum_{s=1}^{p+1} \mathbf{B}_{is}\mathbf{z}_{i,t-s} + \sum_{s=0}^{p+1} \mathbf{B}_{is}^{*}\mathbf{z}_{t-s}^{*} + \mathbf{v}_{it}, \qquad i = 1, \ldots, n \quad \text{and} \quad t = 1, \ldots, T. \quad (3.6)$$

Here, the effects of the common factor are accommodated through the inclusion of the current and lagged values of the global variable in a VARX* model, treating the global variable as exogenous. In practice, the $\mathbf{z}^*$ variables used in model (3.6) can be defined using country-specific weights, $\mathbf{z}_{it}^* = \sum_{j=1}^n w_{ij}\mathbf{z}_{jt}$, where the weights are chosen so that the foreign variable better captures the influence of different countries on country i (using trade volumes or some other metric, for example). Similarly, the order of the lags of $\mathbf{z}_{it}$ and $\mathbf{z}_{it}^*$ do not have to be the same. But in any case, the national model in (3.6) provides a straightforward means of incorporating global influences on a country's output, either exerted alongside the other macroeconomic influences captured by the direct measures of expectations included in $\mathbf{z}_{it}$'s or through the common global factors proxied by the inclusion of the weighted cross-sectional averages.

The final stage in the construction of a GVAR explaining actual and expected outputs across the n countries is motivated by noting that we can

[5] These effects are in addition to the common factors captured by the direct measures of expectations published at $t-1$.

stack the country-specific series into a single vector $\mathbf{z}_t = (\mathbf{z}'_{1t}, \ldots, \mathbf{z}'_{nt})'$ and that we can write $\mathbf{z}^*_{it} = \mathbf{w}_i \mathbf{z}_t$ where $\mathbf{w}_i$ contains country i weights. Arranging the individual vectors of weights in $\mathbf{W}$, the n country-specific models in (3.6) can be stacked to write

$$\mathbf{z}_t = \mathbf{B}_0 + \sum_{s=1}^{p+1} \mathbf{B}_s \mathbf{z}_{t-s} + \sum_{s=0}^{p+1} \mathbf{B}^*_s \mathbf{W} \mathbf{z}_{t-s} + \mathbf{v}_t, \qquad t = 1, \ldots, T, \tag{3.7}$$

and so

$$\mathbf{z}_t = (\mathbf{I} - \mathbf{B}^*_0 \mathbf{W})^{-1} \left(\mathbf{B}_0 + \sum_{s=1}^{p+1} (\mathbf{B}_s + \mathbf{B}^*_s \mathbf{W}) \mathbf{z}_{t-s} + \mathbf{v}_t \right), \qquad t = 1, \ldots, T, \tag{3.8}$$

providing a GVAR model that explicitly models all the interdependencies that exist between actual and expected outputs in all n countries.

3.3 Modelling output fluctuations and recession in the G7

The empirical work of the chapter focuses on actual and expected output data for the G7 economies (Canada, France, Germany, Italy, Japan, UK, and the US) obtained over the period 1994q1–2011q2.[6] The expectations data for each country are taken from issues of *Consensus Forecasts: A Digest of International Economic Forecasts*. The surveys are published monthly by Consensus Economics and contain compilations of country economic forecasts along with the mean of these forecasts. Our quarterly measures of expected output are based on the mean forecasts taken from surveys published midway through the quarter; in February, May, August, and November. In quarter t, this source provides data on growth in GDP in country i expected for the year to the current quarter (i.e. a measure of ${}_t y^c_{it} - {}_t y^c_{i,t-4}$, where the superscript c denotes that the measure is from the *Consensus Forecasts*) and on expected growth in the year to the next quarter (i.e. a measure of ${}_t y^c_{i,t+1} - {}_t y^c_{i,t-3}$).[7]

The actual output data employed in our analysis is the real-volume GDP index for each country taken from the IMF's *International Financial Statistics 2011q3*. This is the most up-to-date and most accurate measure of actual output that we have available at the time of writing. In fact, data on a country's actual output is released with a one-quarter delay (typically in the second month of the following quarter) and is then subsequently revised,

[6] The sample size is limited by the availability of expectations data.

[7] In fact, expectations of growth up to eight quarters ahead are provided, but we focus on the contemporaneous and one-period-ahead measures only.

sometimes by relatively large amounts, for up to two years.[8] Our decision to use only the most recent ($T = 2011q3$) vintage of data in measuring actual output reflects our intention to abstract from the effects of data revisions and to focus on the role of the survey expectations data in our analysis.[9] Hence our measure of the first release of the actual output series ${}_t y_{i,t-1}$ is taken to be the same as the final vintage ${}_T y_{i,t-1}$, assuming that there are no revisions between t and the end of the sample period. We construct the corresponding series of expected output levels data for each country using the final vintage series with the *Consensus Forecasts* of growth in a straightforward way; for example, we construct our measure of expected contemporaneous output ${}_t y^e_{it} = {}_t y^c_{it} - {}_t y^c_{i,t-4} + {}_T y_{i,t-4}$. This data manipulation effectively assumes that the 'true' actual output series is released with a one-quarter delay and is not subsequently revised and that individuals know the true value of output up to one-quarter previously and that it is their expectations of growth in the true output series that is reported in the surveys.

3.3.1 *The national VAR models*

A preliminary data analysis showed that the (logarithm of the) actual output data are integrated of order 1 (i.e. the series needs to be differenced—once—in order to achieve stationarity). It also showed that the expectational errors, ${}_{t+1}y_{it} - {}_t y^e_{it}$ (the difference between the true output level at t and the published nowcast at t) and ${}_{t+1}y_{it} - {}_{t-1}y^e_{it}$ (the difference between the true output level at t and the one-period ahead expectation published at $t-1$) are stationary.[10] This ensured that the modelling framework set out in (3.1) is appropriate.

Table 3.1 illustrates the results obtained for the particular sample running $t = 1994q1$–$2011q2$. The mean actual quarterly growth rate varies from 0.20% in Japan to 0.68% in Canada over this period, but it is clear that there is considerable volatility in growths across all countries, with one standard deviation of the actual quarterly rate ranging from 0.56% in France up to 1.10% in Japan. There are differences between the means of the actual and expected growth series within each country, but these are small relative to the overall volatility of the series so there is no reason to doubt the reasonableness of the survey data on these grounds. The standard deviation of the expected growth series are, in every case, smaller than the standard

[8] The data are also liable to periodic large benchmark revisions in which the method of measurement is changed. See Lee et al. (2012) for an illustrative discussion.

[9] This is not to underplay the potential importance of revisions in the real-time analysis of business cycles; see Orphanides and van Norden (2002) and Garratt et al. (2008, 2009) for detailed discussion of the effects of revisions on measures of the output gap for example.

[10] Standard augmented Dickey–Fuller (DF) unit root tests and Pesaran's (2007) cross-sectionally augmented DF tests were applied. Details of the tests are available on request.

Table 3.1. Summary statistics for estimated national VAR models, 1994q1–2011q2.

	$_ty_{i,t-1} - {}_{t-1}y_{i,t-2}$				$_ty^e_{it} - {}_ty_{i,t-1}$				$_ty^e_{i,t+1} - {}_ty^e_{it}$			
	μ	σ	R^2		μ	σ	R^2		μ	σ	R^2	
	F_1	F_2	F_3	F_4	F_1	F_2	F_3	F_4	F_1	F_2	F_3	F_4
Canada	0.0068	0.0065	0.66		0.0043	0.0061	0.59		0.0074	0.0039	0.52	
	32.65**	6.21*	1.91*	0.43	31.62**	14.33**	0.01	9.60**	2.80	17.41**	15.32**	16.78**
France	0.0043	0.0056	0.57		0.0047	0.0054	0.48		0.0052	0.0044	0.51	
	0.25	2.58	29.06**	4.14	2.51	53.69**	0.06	2.69	0.02	15.27**	5.38*	27.63**
Germany	0.0037	0.0086	0.50		0.0027	0.0066	0.45		0.0050	0.0043	0.35	
	1.46	1.93	25.08**	2.44	3.61*	39.50**	0.01	4.79	2.84	17.84**	4.80	14.24**
Italy	0.0029	0.0083	0.48		0.0014	0.0072	0.35		0.0052	0.0060	0.32	
	0.58	3.03	15.90**	6.60*	1.64	26.78**	0.23	0.73	2.88	22.90**	6.00*	4.44
Japan	0.0020	0.0110	0.34		0.0022	0.0105	0.22		0.0033	0.0079	0.18	
	0.01	3.99	0.81	5.86*	0.02	21.32**	0.53	1.72	3.96**	15.49**	4.97*	1.04
UK	0.0054	0.0065	0.73		0.0028	0.0065	0.69		0.0059	0.0046	0.46	
	12.15**	3.22	25.04**	2.36	4.26*	125.14**	5.65*	1.23	0.52	18.13**	5.75*	6.16*
US	0.0062	0.0070	0.57		0.0083	0.0066	0.39		0.0054	0.0052	0.41	
	0.02	0.00	18.57**	10.32**	4.33*	38.44**	0.01	0.01	0.08	8.05*	12.16**	11.35**

Notes: μ and σ are the mean and standard deviation of the dependent variable; $\bar{R}^2$ is the adjusted R^2; $F_1 - F_4$ tests insignificance of various combinations of variables. See text for details.

deviation of actual growth, which shows a conservatism in expectations formation that is entirely in line with a reasonable (including 'rational') expectation formation process.

Table 3.1 also shows that, for the final sample at least, the fit of the three equations is reasonably good. For actual growth, the $\overline{R}^2$ ranges from 0.48 to 0.73 across the seven countries, averaging at 0.54. The average across the G7 for the expected current growth regressions is 0.45 and the average is 0.39 for the expected future growth regressions. The fit of the three regressions falls as we move into the future, as might be anticipated, but it remains reasonably high throughout.

The table also reports Wald tests of various combinations of zero restrictions to gain insights on the relative explanatory power of the different regressors in the system, distinguished according to whether they relate to actual or expected growth and to nation-specific or starred G7-wide growth. Specifically, F_1 tests the insiginificance of the lagged values of ${}_ty_{i,t-1} - {}_{t-1}y_{i,t-2}$ (cf. χ^2_1); F_2 tests the insignificance of the lagged values of ${}_ty^e_{it} - {}_ty_{i,t-1}$ and ${}_ty^e_{i,t+1} - {}_ty^e_{it}$ (cf. χ^2_2); F_3 tests the insignificance of the ${}_ty^*_{i,t-1} - {}_{t-1}y^*_{i,t-2}$ (cf. χ^2_1); and F_4 tests the insignificance of the ${}_ty^{e*}_{it} - {}_ty^*_{i,t-1}$ and ${}_ty^{e*}_{i,t+1} - {}_ty^{e*}_{it}$ (cf. χ^2_2). The tests of the restrictions in the regression explaining actual growth show quite strikingly the importance of accommodating inter-country interactions in an explanation of national output growths. The $({}_ty^*_{i,t-1} - {}_{t-1}y^*_{i,t-2})$ variable shows very significantly in all of the actual growth equations other than Japan's, reflecting very strong contemporaneous feedbacks across countries' growths. These effects are compounded in some countries by a substantial and significant influence from the G7-wide expectations variables too. In contrast, the nation-specific variables perform relatively poorly in most countries in the actual output equations, confirming the often-made observation that output time series taken in isolation can usually be characterized by very simple autoregressive representations (including that growth is a random walk with drift).

This is not to say that the countries' output dynamics are entirely driven by global influences. The regressions for the expected growth series in each country show actual or expected nation-specific variables to be significant in every one of the 14 regressions, explaining the expected contemporaneous and expected future growths, so capturing strong country-specific effects. Intuitively, it appears that, while the actual growth regressions help to identify the considerable cross-country interdependence in business-cycle *innovations*, it is easier to identify the country *dynamics* through the less-volatile expectations data. The results suggest that, when taken together as a system, there will be extremely complicated interactions between countries' growth, on impact, and over the intermediate and long run. The GVAR modelling framework is invaluable in this context.

3.3.2 *Nowcasting national and G7-wide recessions*

The separate country-level systems can be brought together in a single G7-wide system using the GVAR methods outlined in (3.5)–(3.8) and used in an analysis of recession in the G7. We have argued that the definition of 'recession' and the features of the business cycle that are considered important differ from individual to individual according to the decisions that they need to make. In what follows, we focus on the use of our model to provide a real-time assessment of whether current output growth is negative. As actual output data is released with a one-quarter delay, there is no official measure available for the level of output produced in the current quarter and some individuals will find it useful to 'nowcast' whether today's actual output level is higher or lower than it was last period.

Taking the data for actual output for the G7 countries together over the 70 observations in our sample 1994q1−2003q4, negative output growth is observed in $89/280 = 32\%$ of the observations. This figure may seem high at first sight, but it is influenced by slow growth in Germany in the 1990s and by Japan's poor growth performance over the whole sample. The figure drops to 22% over the period 2003q4–2011q2 that we focus on below. It is perhaps obvious but worth observing that, in practice, a quarter of negative growth is often followed by another quarter of negative growth, as one would expect if there is a reasonably smooth cycle. Over the whole sample, two consecutive quarters of negative growth were observed on $36/280 = 13\%$ occasions and on 12% of occasions in our smaller sample covering the recent financial crisis.

In the forecasting exercise, the system of equations described in (3.1) was estimated, for each country in turn, recursively starting with the sample $t = 1994q1–2003q4$ and then extending the sample until it covered $t = 1994q1–2011q2$. The choice of these sampling periods is relatively arbitrary, balancing the desire to maximize the forecast evaluation period against the need to have a decent sample size to estimate the model at the start of the evaluation period. Given the one-quarter publication delay, the actual output data in the first recursion consisted of $\{{}_{1994q1}y_{i,1993q4}, \ldots, {}_{2003q4}y_{i,2003q3}\}$ and a one-step-ahead forecast of actual output obtained from the estimated model is the nowcast of the first-release observation for 2003q4; namely $E[{}_{2004q1}y_{i,2003q4} \mid \Omega_{2003q4}]$. As we move through the sample, we can produce a whole series of one-step-ahead nowcasts for the evaluation period $2003q4–2011q2$.[11]

[11] Of course, attention does not have to be restricted to one-step-ahead forecasts and, indeed, longer horizon forecasts are necessary to investigate business-cycle features like the output gap. These issues are pursued in more detail in Garratt et al. (2012).

3.3.2.1 COUNTRY-SPECIFIC EVENTS: NATIONAL RECESSION

Figures 3.1–3.7 plot two sets of forecast probabilities of negative contemporaneous growth for each country over the evaluation period. One set is based on the full GVAR model obtained by estimating the systems in (3.1) for each country, as described in Table 3.1, and then stacking these together as in (3.5)–(3.8). The other set is based on a 'benchmark' country-by-country autoregressive model in which the actual output growth in each country is explained solely in terms of its own lagged values. The figures also show the quarters in which growth was indeed negative through the shading. It is worth emphasizing that the event considered in this exercise is not the one most likely to illustrate the benefits of the GVAR framework. As noted, the event occurs on only 22% of occasions, so an unchanging forecast that the event will never happen would be correct on 78% of occasions and randomly guessing according to the unconditional probability would provide a hit-rate of 66%. Given that negative and positive growth is observed in runs, a simple model that forecasts growth to be equal to last period's growth would also perform well. Establishing the usefulness of a statistical model is particularly challenging in this context.

Despite these caveats, the GVAR model appears to perform well in the figures, which are, of course, dominated by the experiences in the run up to the financial crisis of 2008 and its aftermath. All the countries of the G7 experienced quarters of negative growth during the crisis, although the experiences differed according to their start date and duration. Some countries also experienced briefer periods of negative growth at the start of the evaluation period. The diagrams show that the nowcast probabilities of the GVAR model reflect the periods of negative growth reasonably well. The probabilities are correctly small during the long periods of positive growth but respond fairly quickly and decisively to reflect the downturns of the financial crisis. The first period of the negative growth observed during the crisis is typically not picked up by the model, but probabilities quickly rise to more than 0.5 (so that the model predicts the event is more likely to occur than not) very early in the crisis and the probabilities typically drop back below 0.5 contemporaneously, with actual growth rising above zero as economies emerged from the crisis. A useful comparison is with the probabilities of the benchmark model. These have a similar sort of shape, reflecting the fact that even a simple autoregressive model can capture a once-and-for-all shift well, but the timings are clearly less accurate than those of the GVAR model.

The performance of the models is described more formally in the statistics of Table 3.2. This provides, for each country, the hit-rate (i.e. the proportion of accurate predictions), the Kuipers score (a statistic that takes values between –1 and 1 and summarizes the degree of correspondence between

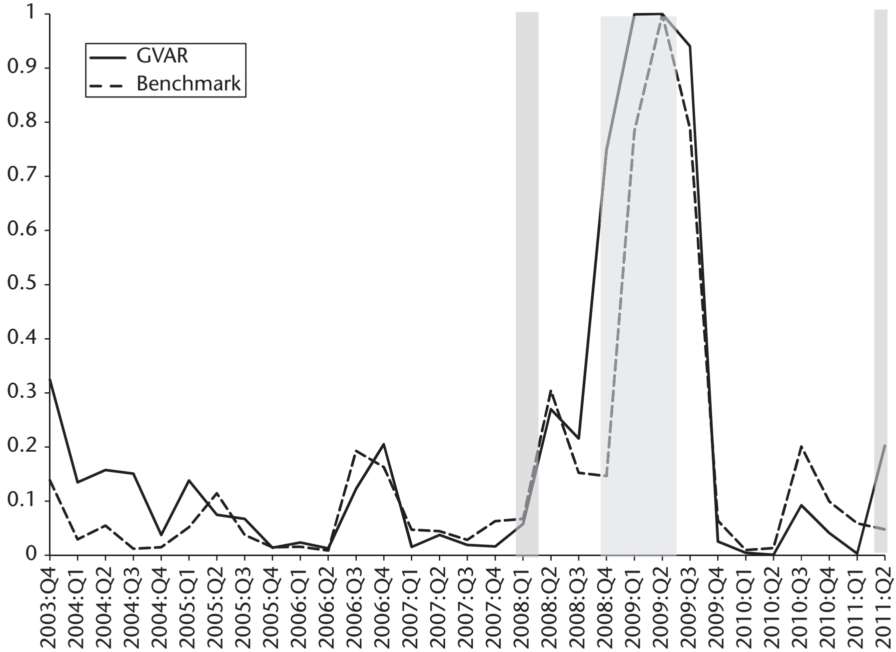

Figure 3.1. Nowcast probability of negative growth, Canada.

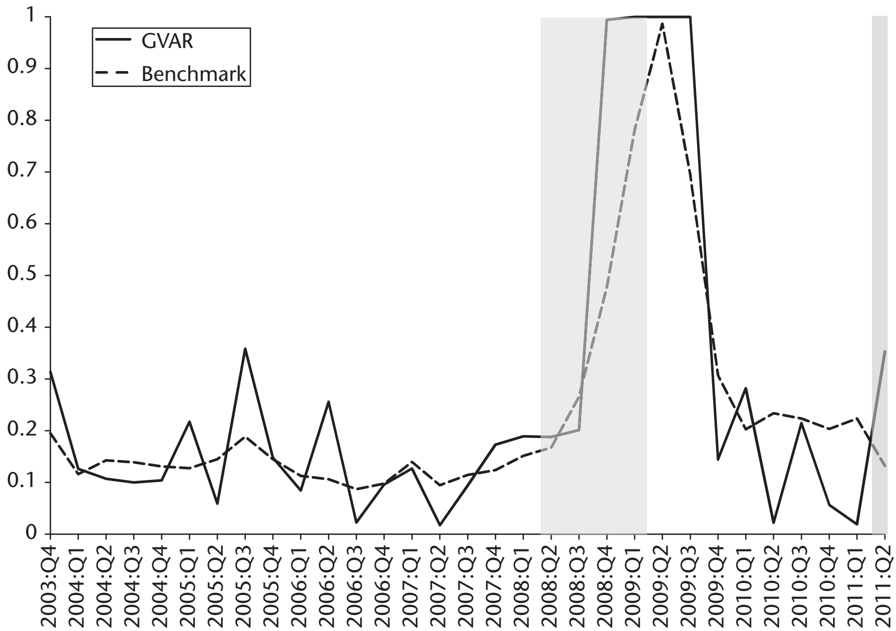

Figure 3.2. Nowcast probability of negative growth, France.

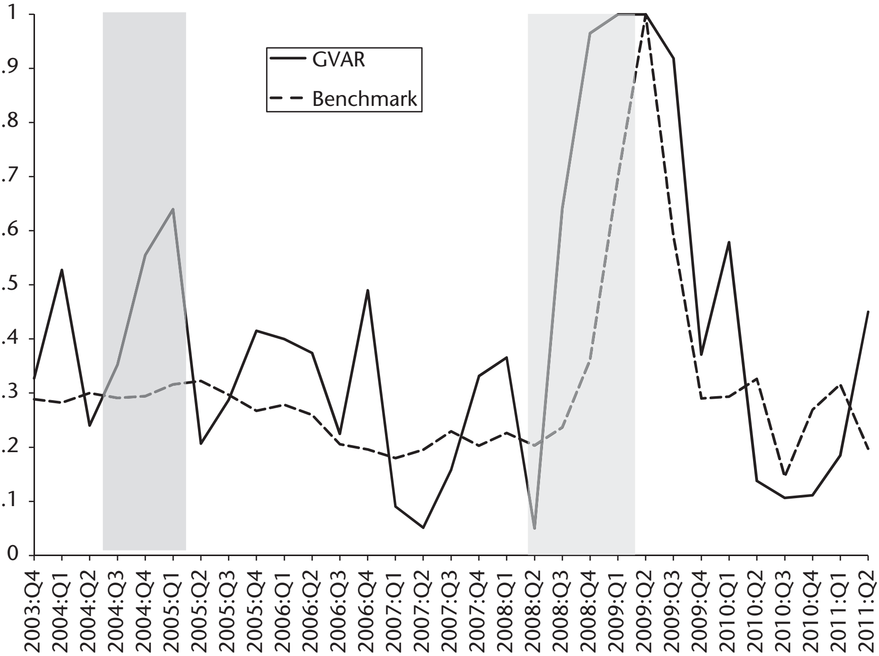

Figure 3.3. Nowcast probability of negative growth, Germany.

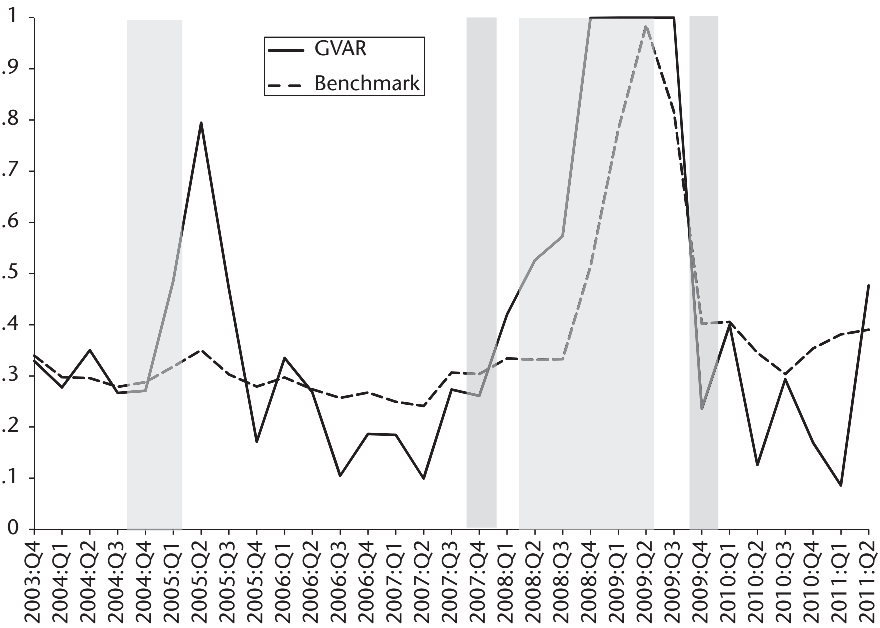

Figure 3.4. Nowcast probability of negative growth, Italy.

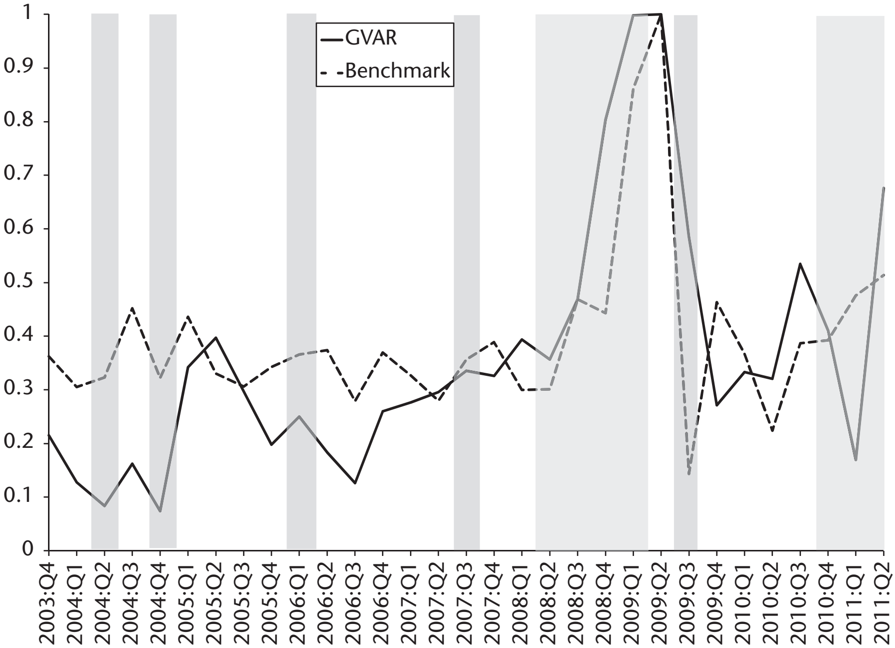

Figure 3.5. Nowcast probability of negative growth, Japan.

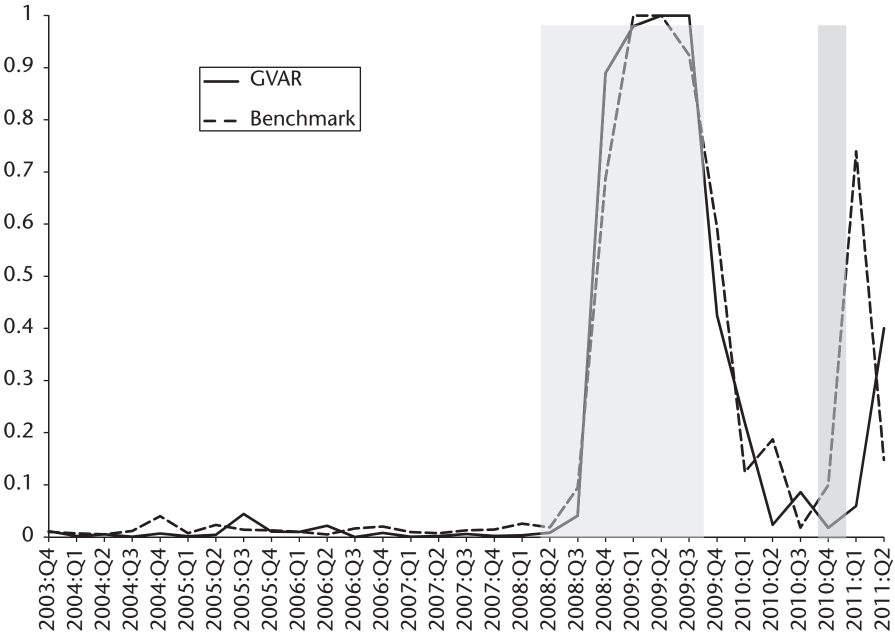

Figure 3.6. Nowcast probability of negative growth, UK.

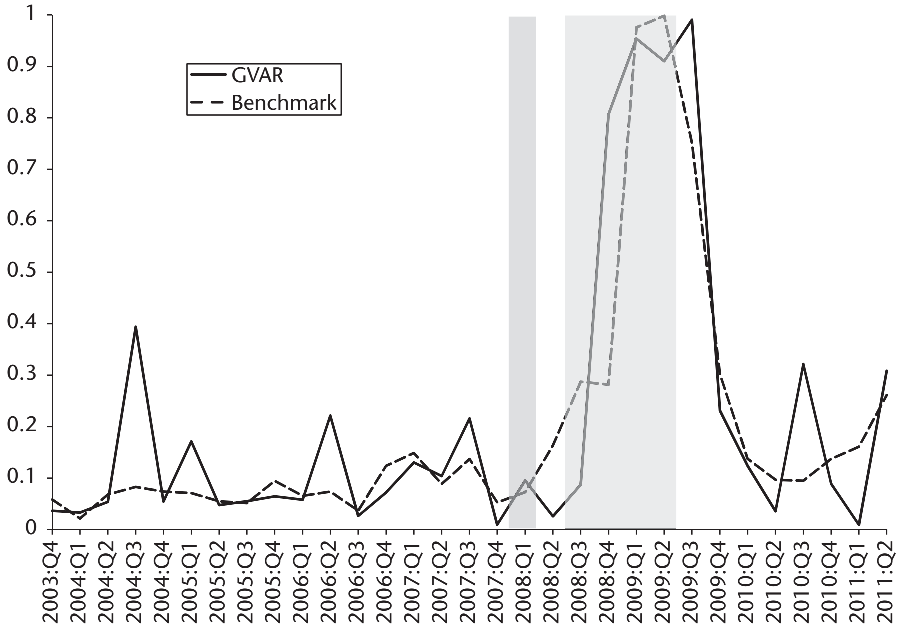

Figure 3.7. Nowcast probability of negative growth, US.

Table 3.2. Nowcast probabilities of negative growth; performance statistics.

	Benchmark model				GVAR model			
	HR	*KS*	Static χ^2	Dynamic χ^2	*HR*	*KS*	Static χ^2	Dynamic χ^2
Canada	0.900	0.593	7.867**	4.448**	0.933	0.712	14.619**	11.617**
France	0.833	0.222	1.074	0.123	0.867	0.423	5.116**	0.000
Germany	0.767	0.148	0.326	0.570	0.800	0.346	2.429	0.611
Italy	0.767	0.519	4.190	0.086	0.800	0.540	7.034**	1.545
Japan	0.633	0.143	0.133	0.034	0.667	0.280	1.250	0.467
UK	0.833	0.542	7.472**	1.071	0.900	0.885	14.583**	7.427**
US	0.867	0.556	5.729**	0.997	0.900	0.673	10.848**	4.874*
G7 (country av.)	0.833	0.222	1.074	0.123	0.867	0.423	5.116**	0.000
G7 (country count)	0.867	0.556	5.729**	0.538	0.900	0.673	10.848**	0.164

Notes: HR denotes the hit-rate; KS denotes the Kuiper score; static χ^2 is the standard reduced rank regression test of no association between prediction and outcome; dynamic χ^2 is the corresponding test taking into account the possibility of runs of outcomes of the same type (see text for details).

predictions and outcomes, rather like a correlation coefficient), and two χ_1^2 tests to test the null that there is no relationship between the outcome and the prediction that the event will occur (taken to mean that the probability exceeds 0.5). The tests are the reduced rank regression and dynamically augmented reduced rank regression tests described in Pesaran and Timmermann

(2009). The former test is equivalent to a standard contingency-table test, while the second takes into account the possibility that there are predictable runs in the data. The reported hit-rates and Kuipers scores for the GVAR models average 0.83 and 0.55 and are larger than those from the benchmark model in every country. The standard contingency-table test shows that the accuracy of the GVAR model-based predictions are statistically significant in all cases other than Japan. (The benchmark model's predictive accuracy is not significant in Germany or France either.) Given the runs of observations observed in the data, it will be harder to reject the null of no predictability in the dynamically adjusted equivalent, but the GVAR model remains significant for Canada, the UK, and the US even against this harsher criterion. (Only the Canadian model is significant in the benchmark case.) In short, the GVAR model performs well in nowcasting negative current period growth. This is all the more impressive given that the probabilities are concerned with a very short one-step-ahead horizon and given the nature of the event under investigation.

3.3.2.2 G7-SPECIFIC EVENTS: GLOBAL RECESSION

Finally here, Figures 3.8 and 3.9 provide corresponding probability forecasts of two related G7-wide events. Figure 3.8 shows the nowcast probabilities that the *average of the growth rates* across the G7 economies falls below zero. Figure 3.9 shows the nowcast probabilities that (any) four or more of the seven countries experience negative output growth, i.e. a G7-wide *country count event*. The intention is to illustrate the flexibility of the modelling framework, and the associated simulations, in highlighting different aspects of the global recession. As it turns out, the two events are indeed closely related, with the country average event occurring four times between 2008q2 and 2009q1, and the country count event occurring five times in 2008q2–2009q2. As in the country-specific events, the GVAR model nowcasts the events reasonably well and performs substantially better than the benchmark model, according to the statistics in Table 3.2, with higher hit-rates and Kuipers scores and with clear support for the accuracy of the GVAR, at least in the static reduced rank regression test.

3.4 Concluding remarks

This chapter presents a simple VAR analysis of the actual and expected output growths in the G7 economies. The potentially complicated interactions between countries are captured by the careful construction and use of 'starred' G7-wide aggregates in the models and through the use of direct measures of expectations, which will automatically incorporate the expected

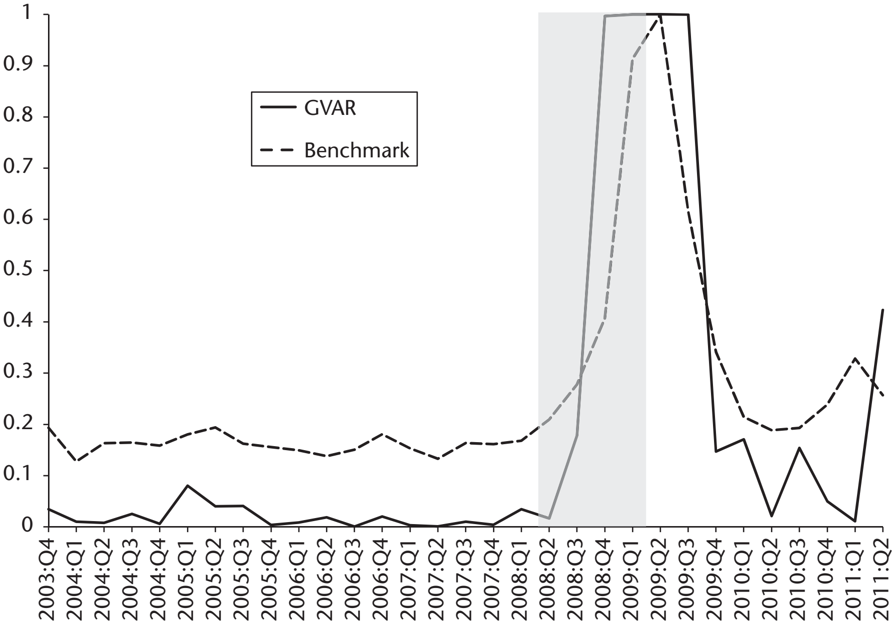

Figure 3.8. Nowcast probability of negative growth, G7 country average.

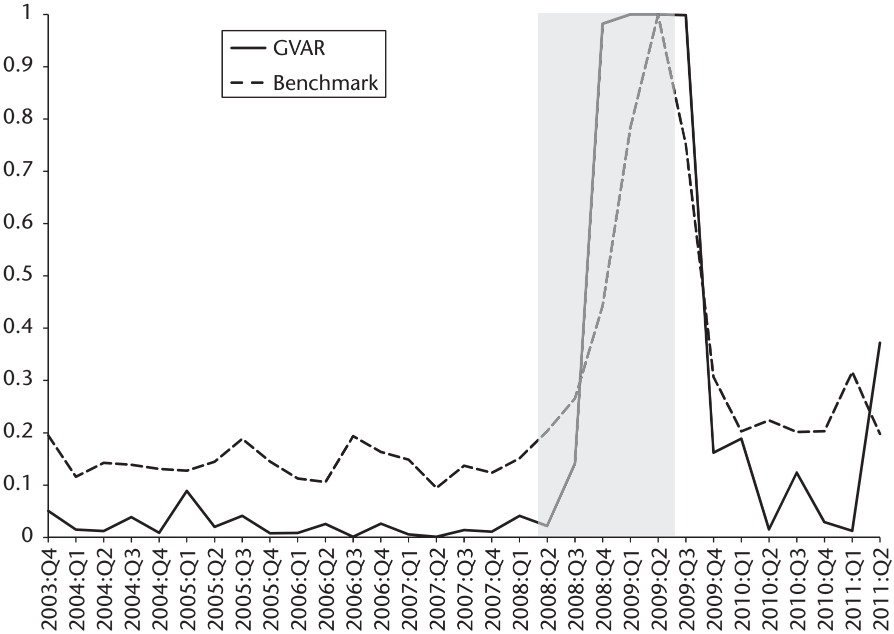

Figure 3.9. Nowcast probability of negative growth, G7 country count.

effects of external influences on domestic output. Indeed, we argue that the use of direct survey-based measures of expectations is a very parsimonious use of information, reflecting the effects of *all* the influences that are relevant to growth determination. This is achieved in a model that has a meaningful economic interpretation—one that is lost when complex information is summarized through statistical dynamic factors, for example—but is not vulnerable to the potentially contentious assumptions underlying structural (including long-run structural) models.

The complex dynamic interactions captured by the estimated national relationships are organized through the GVAR framework into a single coherent system. This is extremely useful for investigating the dynamic cross-country interactions and to make forecasts. Focusing on a relatively demanding forecasting exercise (in which the event occurs rarely, and when it does it occurs in runs), we use the GVAR model to nowcast the probabilities of negative output growth in the current period. The results show that the model performs well and will be very useful for making decisions where there is a premium on understanding the state of the economy—whether there is a national or global recession taking place—at the earliest opportunity.

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4

The GVAR approach to structural modelling

Ron P. Smith

4.1 Introduction

As the other chapters of this handbook indicate, the multi-country, co-integrating global vector autoregression—GVAR—has proved an effective tool in a wide range of applications, including forecasting, counterfactual analysis, and investigating the transmission of shocks across economies or markets. However, as mentioned in Chapter 2, the basic GVAR is subject to the critique that its shocks cannot be given simple economic interpretations as demand, supply, or monetary policy shocks. Dynamic stochastic general equilibrium, DSGE, models do generate shocks that can be given such a simple interpretation, but extending DSGE models to a multi-country framework is not straightforward. Existing open-economy DSGE models tend to consider either two countries of comparable size, such as the euro area and the US or a small, open economy, models where the rest of the world is treated as exogenous. But it is the interactions between many countries that is often crucial for questions about the global economy. Carabenciov et al. (2008, p.6), who consider developing multi-country models, state that: 'Large scale DSGE models show promise in this regard, but we are years away from developing empirically based multi-country versions of these models.' This chapter summarizes some of the main features of the multi-country new-Keynesian, MCNK, model developed in Dées, Pesaran, Smith, & Smith (2011), DPSS. This is a structural, DSGE type model, within a GVAR type of framework, which is used to examine the transmission of domestic and international shocks and to identify the separate contributions of demand, supply, monetary policy, and exchange rate shocks to business-cycle fluctuations.

Developing a multi-country structural model faces a number of difficult issues, including the treatment of the steady states, the determination of exchange rates and the nominal anchor, the estimation method, and the structure and estimation of the covariance matrix. The technical details of the treatment of these issues is discussed in more detail in DPSS; in this chapter the focus is on the general principles. The MCNK model uses an augmented version of a standard three-equation new-Keynesian (NK) model to clarify these issues and to demonstrate how a multi-country rational expectations model can be identified, estimated, and solved. There are other approaches to identification of structural shocks in the literature. These include the structural VARs proposed by Blanchard and Quah (1989) and identification by sign restrictions on the impulse responses proposed by Uhlig (2005). It is unclear how these approaches can be extended to multi-country models, and even for small models these identification schemes have been subject to criticisms. For example, see Carlstrom et al. (2009) on structural VAR identification and Fry and Pagan (2011) on identification by sign restrictions.

Section 4.2 considers the country-specific components of the model. Section 4.3 discusses estimation and solution, section 4.4 analyses the shocks, and section 4.5 concludes.[1]

4.2 The country-specific components of the MCNK model

For each country the MCNK model includes a forward-looking Phillips curve, a Taylor rule, an IS curve (which also includes exchange rate and foreign output gap variables) and, except for the US, a real effective exchange rate equation. The MCNK model is estimated for 33 countries over the period 1980q1–2006q4. Consider $N+1$ countries, indexed by i, where $i = 0, 1, 2, \ldots, N$. The US, $i = 0$, is treated differently, since the US dollar is used as the numeraire currency. Following the NK theory, all variables are measured as deviations from their steady states, but rather than treating the steady states as constants, deterministic trends, or measured by purely statistical univariate de-trending procedures such as the Hodrick–Prescott (HP) filter, the steady states are measured directly from an economic model as the long-horizon forecasts from the co-integrating GVAR. These steady states reflect stochastic trends and co-integrating relations that may exist in the data, yield stationary deviations as required by the theory, and are consistent with the MCNK model.

The deviations from steady state are represented by tildes, so for instance $\widetilde{\pi}_{it}$ is the deviation from steady state of inflation $\pi_{it} = p_{it} - p_{i,t-1}$, where

[1] The data set and code used to obtain the results in this chapter are available online at <https://sites.google.com/site/gvarmodelling/mcnk-modelling>.

p_{it} is the logarithm of the price level. The other variables included are output deviations, $\widetilde{y}_{it}$, interest rate deviations, $\widetilde{r}_{it}$ (except for Saudi Arabia, where an interest rate variable is not available), and real effective exchange rate deviations, $\widetilde{re}_{it}$, except for the US. Country-specific foreign variables are trade-weighted averages of the corresponding variables for other countries. For example, the foreign output deviation of country i is defined by $\widetilde{y}^{*}_{it} = \Sigma_{j=0}^{N} w_{ij}\widetilde{y}_{jt}$, where w_{ij} is the trade weight of country j in the total trade (exports plus imports) of country i. By construction $\sum_{j=0}^{N} w_{ij} = 1$, $w_{ii} = 0$.

With $N+1$ countries there are $N(N-1)/2$ cross-rates, which are aggregated using trade weights to give real effective exchange rates. Deviations from steady state of the logarithm of the real effective exchange rate are included in the IS curves and modelled as N separate autoregressive processes (the US real effective exchange rate being a linear combination of the other N). The model is solved for the logarithm of the nominal exchange rate (as deviations from the steady states) against the US dollar deflated by the domestic price level. For the US, this is just minus the log of the US price level relative to its steady-state value, derived from the US Phillips curve. This provides the nominal anchor.

The Phillips curve (PC) is derived from the optimizing behaviour of monopolistically competitive firms subject to nominal rigidities, which determines inflation deviations $\widetilde{\pi}_{it}$, and takes the form

$$\widetilde{\pi}_{it} = \beta_{ib}\widetilde{\pi}_{i,t-1} + \beta_{if}E_{t-1}\left(\widetilde{\pi}_{i,t+1}\right) + \beta_{iy}\widetilde{y}_{it} + \varepsilon_{i,st},\; i = 0, 1, \ldots, N, \tag{4.1}$$

where $E_{t-1}\left(\widetilde{\pi}_{i,t+1}\right) = E\left(\widetilde{\pi}_{i,t+1} \mid \Im_{i,t-1}\right)$, and $\Im_{i,t-1}$ denotes the information available at time $t-1$. No intercepts are included in the equations, since deviations from steady-state values have mean zero by construction. The error term, $\varepsilon_{i,st}$, is interpreted as a supply shock or a shock to the price–cost margin in country i.

The aggregate demand or IS curve is obtained by log-linearizing the Euler equation in consumption and substituting the result in the economy's aggregate resource constraint. For an open economy model, the aggregate resource constraint will also contain net exports, which in turn will be a function of the real effective exchange rate, $\widetilde{re}_{it}$, and the foreign output gap, $\widetilde{y}^{*}_{it}$. The unrestricted estimates of the forward-looking IS curve resulted in a positive coefficient on the interest rate variable in many countries. Given the importance of the interest rate effects in the standard model, we decided to impose the restriction that the coefficient of future output was zero. Thus the IS equation used in the model is

$$\widetilde{y}_{it} = \alpha_{ib}\widetilde{y}_{i,t-1} + \alpha_{ir}\left[\widetilde{r}_{it} - E_{t-1}\left(\widetilde{\pi}_{i,t+1}\right)\right] + \alpha_{ie}\widetilde{re}_{it} + \alpha_{iy*}\widetilde{y}^{*}_{it} + \varepsilon_{i,dt},\; i = 0, 1, \ldots, N. \tag{4.2}$$

The error, $\varepsilon_{i,dt}$, is interpreted as a demand shock.

The interest rate deviations in country i, $\widetilde{r}_{it}$, are set according to a standard Taylor rule (TR) of the form:

$$\widetilde{r}_{it} = \gamma_{ib}\widetilde{r}_{i,t-1} + \gamma_{i\pi}\widetilde{\pi}_{it} + \gamma_{iy}\widetilde{y}_{it} + \varepsilon_{i,mt}, \; i = 0, 1, \ldots, N. \tag{4.3}$$

The error $\varepsilon_{i,mt}$ is interpreted as a monetary policy shock.

The log real effective exchange rate deviations, $\widetilde{re}_{it}$, are modelled as a stationary first-order autoregression,

$$\widetilde{re}_{it} = \rho_i \widetilde{re}_{i,t-1} + \varepsilon_{i,et}, \; \left|\rho_i\right| < 1, \; i = 1, 2, \ldots, N. \tag{4.4}$$

To the extent that long-run theory restrictions such as purchasing power parity and uncovered interest parity (UIP) are supported by the data, they will be embodied in the co-integrating relations that underlie the global error-correcting model. These will then be reflected in the steady-state and long-horizon expectation, to which the exchange rate adjusts. It is well known that UIP fails to hold in the short-run: high interest rates predict an appreciation of the currency rather than a depreciation, as UIP would imply. This failure gives rise to a large UIP risk premium or carry trade return. Since the model explains the exchange rate and the forward rate (from domestic and foreign interest rates), it implicitly defines this UIP risk premium.

Putting equations (4.1)–(4.4) together for all 33 countries, the total number of variables in the multi-country model is $k = \sum_{i=0}^{N} k_i = 130$, where k_i is the number of variables in country i. For the US, with no exchange rate equation, $k_0 = 3$; for Saudi Arabia, with no interest rate equation, $k_{SA} = 3$; and for the other 31 countries $k_i = 4$. In line with the standard NK model, and unlike the GVAR of Chapter 2, financial variables are not included.

4.3 Estimation and solution

There is no agreement on the appropriate structure or estimation method for DSGE models and, in particular, there is controversy over the appropriate trade-off between coherence with a particular sort of theory and representation of the data. Some, like Chari et al. (2009), criticize NK DSGE models like Smets and Wouters (2007) for having sacrificed theoretical coherence to fit the data; others, like Caballero (2010), De Grauwe (2010), and Pesaran and Smith (2011) argue that the insistence on coherence with a restrictive type of theoretical model comes at a considerable cost. This tension between theory and data is even more apparent in an international context, where one has to choose, for instance, whether to impose uncovered interest parity despite the strong evidence against it.

The estimated NK model may be regarded as structural since, under certain assumptions, its parameters can be related to a set of 'deeper' parameters of technology and tastes such as the discount rate or the risk aversion coefficient of the underlying representative agent. But the nonlinear cross-equation restrictions deriving from the deeper parameters are not imposed, because there is strong evidence of misspecification in these restrictions of the NK model.

NK models are usually estimated either by generalized method of moments, GMM, or Bayesian methods. Bayesian estimation of a multi-country model, where N is large, faces considerable difficulties both in the specification of multivariate priors over a large number of parameters and the numerical issues that arise in estimation of large systems. Thus the MCNK model is estimated by GMM. However, the estimation is subject to a set of inequality constraints reflecting theoretical restrictions. For instance, the coefficient of the output gap in the Phillips curve should be positive, but if the estimate is negative it is constrained to be zero.

There has been some concern in the literature that the parameters of the NK model are not identifed, e.g. Canova and Sala (2009) and Koop et al. (2011). Dées et al. (2009) argue that the large N framework can provide new sources of identification, not available in closed economy models, through the use of cross-section averages of foreign variables as instruments. Individual country shocks, being relatively unimportant, will be uncorrelated with the cross-section averages as N becomes large, whilst global factors make the cross-section averages correlated with the included endogenous variables. The parameters of the multi-country model can be estimated consistently for each country separately by instrumental variables subject to the theory restrictions referred to above. The instruments used are an intercept, the lagged values of the country-specific endogenous variables $\widetilde{y}_{i,t-1}$, $\widetilde{\pi}_{i,t-1}, \widetilde{r}_{i,t-1}, \widetilde{re}_{i,t-1}$, the current values of the country-specific foreign variables $\widetilde{y}^*_{it}, \widetilde{\pi}^*_{it}, \widetilde{r}^*_{it}$, and the log oil price deviation, $\widetilde{p}^o_t$.

The distribution of the estimates together with the constraints imposed on the equations is shown in Table 4.1. As is to be expected, there is a considerable degree of heterogeneity in the estimates of the structural parameters, with those for Latin American countries often being the outliers.

The rational expectations solution of the model can be obtained using standard techniques. However, the multi-country linkages through exchange rates and the role of the numeraire requires a more explicit treatment of the price level. While inflation is determined in each country through the Phillips curve, the price levels enter the real effective exchange rates. Since the US is the numeraire country for exchange rates, the US price-level deviation provides the nominal anchor, $\widetilde{p}_{0,t}$. This is done by distinguishing the vectors used in estimation (which contains both US inflation,

Table 4.1. Distribution of inequality-constrained IV estimates using GVAR estimates of deviations from steady states.

	Mean	# Constrained	UC mean	Constraint
Phillips curve—Equation (4.1), $N = 33$				
β_{ib}	0.12	10	0.17	$\beta_{ib} \geq 0$
β_{if}	0.80	0	0.80	$\beta_{if} \geq 0$
β_{iy}	0.11	7	0.14	$\beta_{iy} \geq 0$
$\beta_{ib}+\beta_{if}$	0.93	22	0.80	$\beta_{ib}+\beta_{if} \leq 0.99$
IS curve—Equation (14.4), $N = 33$				
α_{ib}	0.27	0	0.27	
α_{ir}	−0.20	18	−0.43	$\alpha_{ir} \leq 0$
κ_{ir}	−0.35		−0.43	
α_{ie}	0.02	0	0.02	
κ_{ie}	0.12		0.05	
α_{iy*}	0.79	2	0.84	$\alpha_{iy*} \geq 0$
κ_{iy*}	1.17		1.18	
Taylor rule—Equation (4.3), $N = 32$				
γ_{ib}	0.59	0	0.59	
$\gamma_{i\pi}$	0.24	4	0.28	$\gamma_{i\pi} \geq 0$
$\mu_{i\pi}$	0.77		0.36	
γ_{iy}	0.06	11	0.09	$\gamma_{iy} \geq 0$
μ_{iy}	0.27		0.17	
Exchange rates—Equation (4.4), $N = 32$				
ρ_i	0.67	0	0.67	$\lvert\rho_i\rvert < 1$

Note: The estimation sample begins in $t = 1980Q1$ and ends in 2006Q3 for the PC and IS equations, and 2006Q4 for the Taylor rule and exchange rate equations. An exception is the Phillips curve in Argentina, which is estimated over the subsample 1990Q1–2006Q3. N is the number of countries for which the equations are estimated. The column headed 'Mean' gives the average over all estimates, constrained and unconstrained. The column headed '# Constrained' gives the number of estimates constrained at the boundary. The column headed 'UC mean' gives the mean of the unconstrained estimates. The κ_i are the long-run coefficients in the IS curve, and the μ_i the long-run coefficients in the Taylor rule.

$\widetilde{\pi}_{0,t}$, and price level $\widetilde{p}_{0,t}$), and the vector used in solution, where the redundant equation is removed. The MCNK model is solved for all time periods in the estimation sample, giving estimates of the 130 shocks; 98 structural and 32 reduced-form exchange rate shocks. Because of the size and complexity of the model, one cannot derive analytical conditions for the existence of a unique determinate solution. In fact, for these estimates, which impose a set of theoretical restrictions, a unique determinate solution does exist.

The estimates of the structural parameters can be used to estimate the country-specific supply, demand, and monetary policy shocks $\varepsilon_{i,st}$, $\varepsilon_{i,dt}$, and $\varepsilon_{i,mt}$. It is assumed, following the literature, that these shocks are pairwise orthogonal within each country, but shocks of the same type may be correlated across countries. In a multi-country context it does not seem plausible to assume that shocks of the same type are orthogonal across countries. Consider neighbouring economies with similar experiences of supply disruptions, or small economies that are affected by the same supply shocks originating from a dominant economy. As discussed in Pesaran and Chudik (2010), it is possible to deal with such effects explicitly by conditioning the individual country equations on the current and lagged variables of the dominant economy (if any), as well as on the variables of the neighbouring economies, as was partly done in the specification of the IS equations. But since following such a strategy more generally would move the equations away from the standard NK model, the cross-country dependencies are assumed to operate through suitably restricted error spillovers.

The exchange rate shocks, $\varepsilon_{i,et}$, defined by (4.4), can respond to all the other shocks through non-zero cross-error correlations both within and across the countries. This yields the main case considered: a block diagonal error covariance matrix, which is bordered by non-zero covariances between $\varepsilon_{i,et}$ and $(\varepsilon_{i,st}, \varepsilon_{i,dt}, \varepsilon_{i,mt})$.

The analysis of the effects of shocks will be represented, as usual, by impulse response functions, IRFs, and forecast error variance decompositions, FEVDs. Error bands are provided by bootstrapping the model. The IRFs and FEVDs depend on the structure of the covariance matrix. These proportions will not add up to unity, due to the error spillover effects between the real effective exchange rates and the three structural shocks. But due to the relatively small magnitudes of the covariance terms between the real exchange rates and the structural shocks, the proportion of forecast error variances explained by variances of the four shocks add to a number that is very close to unity.

Table 4.2 provides averages of pairwise correlations across the four types of shocks, computed by averaging, for instance, over the $(33 \times 32)/2 = 528$ pairs of correlation coefficients from the 33 supply shocks, and the $(33 \times 34)/2 = 561$ pairs of supply–demand shocks.

The largest average correlations are among supply shocks, at 0.495; the other correlations are all less than 0.17. By comparison, the average pairwise correlations of shocks of different types (given as the off-diagonal elements in Table 4.1) are small, with the largest figure given by the average correlation of demand-and-supply shocks given by 0.166. The other average correlations across the different types of shocks are small. This is in line with the assumption that supply, demand, and monetary policy shocks are orthogonal.

Table 4.2. Average pairwise correlations of shocks.

	Supply	Demand	Mon. pol.	Ex. rate
Supply	0.495	0.166	0.040	0.048
Demand		0.067	0.063	−0.005
Mon. pol.			0.139	−0.043
Ex. rate				0.049

In calculating the IRFs and FEVD, a bordered covariance matrix is used with non-zero covariances between structural shocks of the same type, and with unrestricted covariances between the structural shocks and exchange rate shocks. There is a difficulty that since the dimension of the endogenous variables, 130, is larger than the time-series dimension, $T = 108$, this covariance matrix is not guaranteed to be positive definite. This was dealt with by shrinking the estimated matrix towards its diagonal until a positive definite matrix was obtained.

4.4 Analysis of shocks

The impulse responses measure the effects of an unexpected one-period shock not on the variables, but on their deviations from steady states. To examine the effects of shocks on the variables themselves, one would also need to consider the changes in their steady states. The system is stable, and following these shocks the variables converge to their steady-state values within 5–6 years in the vast majority of cases. Although there are only short lags in the system, no more than one period, and strongly forward-looking behaviour in the Phillips curve, there is complicated dynamics and some slow adjustment to shocks. The largest eigenvalue of the system is 0.975. Many of the eigenvalues are complex, so adjustments often cycle back to zero. Inflation is a forward-looking variable in this model, so it jumps as expectations adjust to a shock, while interest rates respond strongly to inflation.

The effects of a contractionary US monetary policy shock on interest rates, inflation, and output are shown in Figures 4.1–4.3. It raises the US interest rate on impact by one standard error (around 22 basis points per quarter), which also simultaneously impacts interest rates in other countries through the contemporaneous dependence of monetary policy shocks. The mean change for other countries amounts to an increase of 6 basis points, though this is skewed by some large Latin American responses, and the median is 2 basis points. Interest rates then move below their steady-state values very quickly to offset the shock and by quarter 4 they are lower almost everywhere, by -15 basis points in the US; for the other countries the mean is -16 basis points, and the median -10 basis points. The effect of the monetary policy shock on interest rates in other countries is of the same order of magnitude as in the US. All the interest rates are close to their steady-state values within five years, except for the interest rates in Norway, which take longer to settle down.

The US monetary policy shock depresses inflation and output, which is consistent with the standard results, and output and inflation return to close to steady state within five years for inflation, and six years for output. By quarter 4, US inflation is −0.18% and US output −0.50% below their steady-state values. The reduction in US inflation and output in response to the monetary policy shock has a similar shape to that of Smets and Wouters (2007, Fig. 6). The major difference is that whereas in their model a monetary policy shock causes interest rates to go up then slowly return to zero, in our model the monetary policy shock initially raises interest rates, but this is quickly offset by the effects of the relatively sharp falls in output and inflation. This rapid stabilizing response occurs despite the fact that there is quite a lot of inertia in our Taylor rules, which have a coefficient of lagged interest rate that averages 0.59. The effects on inflation and output in other countries are similar to those in the US. On average after four quarters, inflation in countries other than the US is lower by −0.18% (per quarter), the same as the US, and output is lower by −0.64%, rather more than the US. The US variables tend to return to their steady-state values relatively quickly compared to other countries. The results show that a US monetary policy shock has a rather large global impact in this model.

Next consider a global inflationary supply shock, $\mathbf{a}_s'\boldsymbol{\varepsilon}_t^0$, where the non-zero elements of $\mathbf{a}_s$ are PPP GDP weights (that add up to one), associated with the $N+1$ supply shocks, $\boldsymbol{\varepsilon}_{i,st}$, in $\boldsymbol{\varepsilon}_t^0$. The supply shock causes inflation and interest rates to increase on impact, but then they both fall below their steady-state values relatively rapidly, before slowly returning back to the steady states. The global supply shock has quite a large impact. In the US, the supply shock increases inflation by 1.4%, which is then reversed to −1.4% after two quarters, before returning to its steady-state value. The pattern is similar across other countries, though the impact effect on the US is rather higher than the average increase in inflation experienced in other countries, which is 1.0% rather than 1.4% in the US. Similarly, the reduction in US inflation after two quarters is rather larger than the average fall in inflation in other countries.

The global supply shock also reduces output across the board, with an average effect of −2.4% after four quarters. The pattern of dynamic adjustments to the global supply shock is different from the standard closed economy models because cross-variable feedbacks seem to operate at a faster pace: inflation and interest rates rapidly move to offset the effects of the inflationary pressure resulting from the global supply shock.

A global demand shock (constructed similarly to the global supply shock using PPP GDP weights) has a positive effect on output, inflation, and interest rates. In accord with the theory, in the MCNK model a global demand shock increases output and inflation, while a supply shock reduces output and increases inflation. The global demand shock causes output and interest

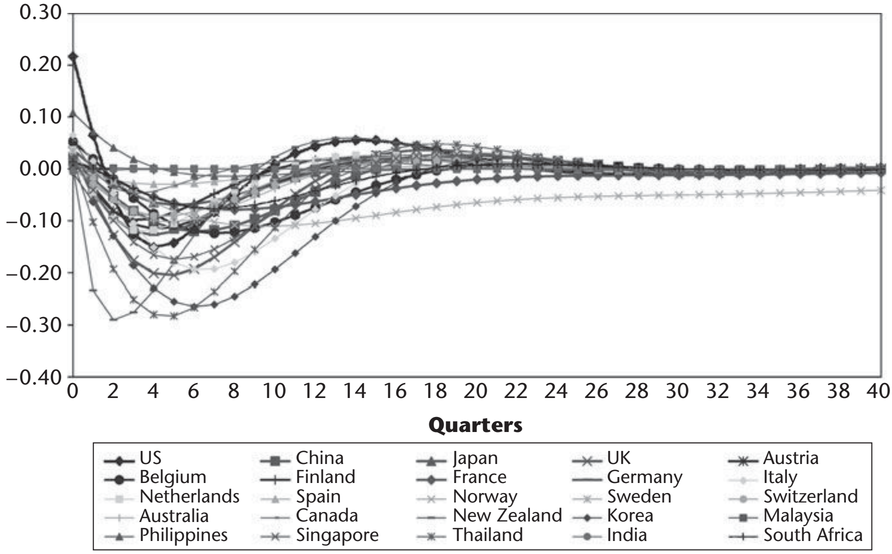

Figure 4.1. Impulse responses of a one-standard-error US monetary policy shock on interest rates (per cent per quarter).

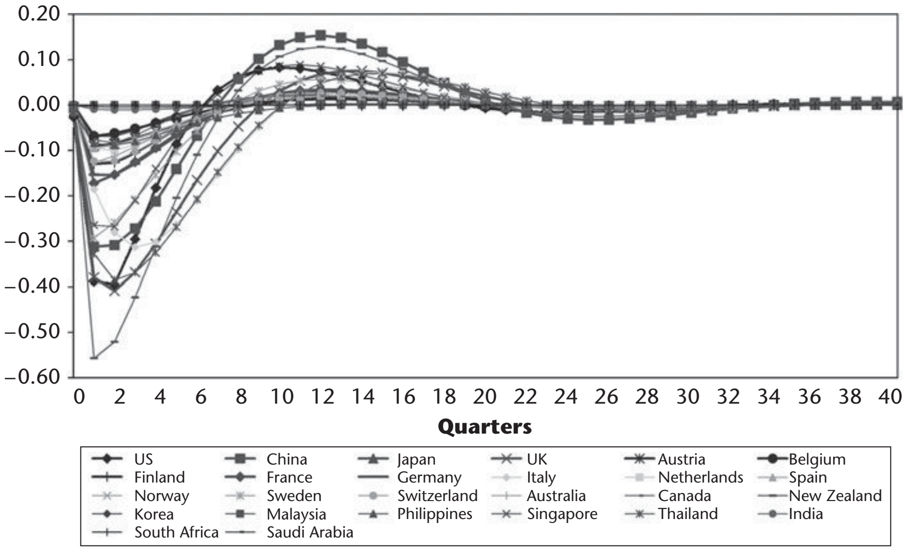

Figure 4.2. Impulse responses of a one-standard-error US monetary policy shock on inflation (per cent per quarter).

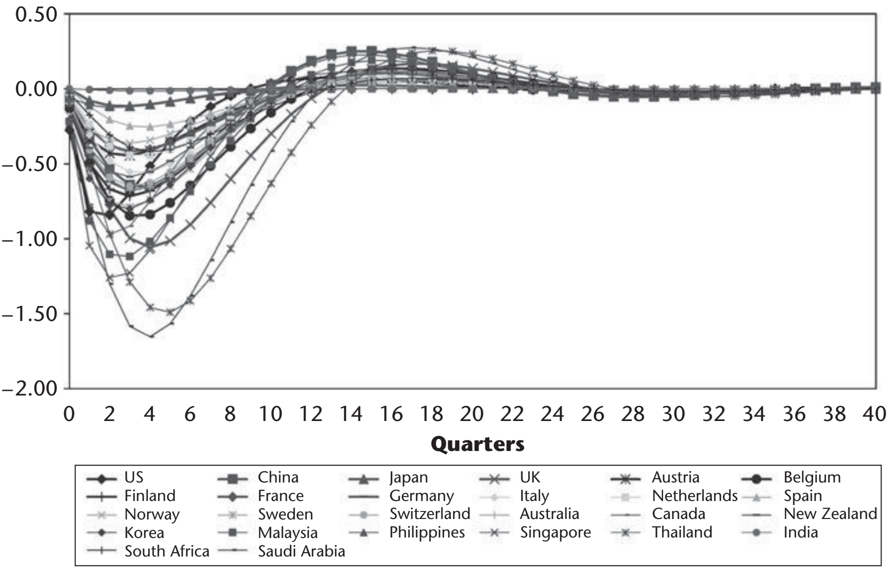

Figure 4.3. Impulse responses of a one-standard-error US monetary policy shock on output (per cent per quarter).

rates to rise before cycling back to their steady-state values. The initial expansionary phase of the shock is relatively long-lived and takes around 11–15 quarters. The effects of the demand shock across countries are qualitatively similar, but differ markedly in the size of the effects. The effect on US output of 3.7% is in the middle of the cross-country distribution of the effects, with the US output returning to its steady-state value relatively fast. In some other countries output increases further after impact, before returning to steady state. The positive effect on inflation lasts a somewhat shorter period than on output. The shape of the responses by output, inflation, and interest rates in the US, to the demand shock are qualitatively similar to those reported by Smets and Wouters (2007, Fig. 2)

The FEVDs across the different variables add up close to unity, being a little below on impact and a little above after 12 quarters on average. While there are differences across countries, in all cases supply and demand shocks account for most of the variations in output, inflation, and interest rate in the long run, with monetary policy shocks and exchange-rate shocks accounting for relatively little of the variations—around 8–10% each. Monetary policy shocks account for more of the variation in interest rates in Canada than in other countries, though even here it is not a large proportion. On impact supply shocks account for nearly all the variation of inflation, but this drops rapidly and these shocks only account for about half of the variation of inflation in the long run. Demand shocks account for most of the variations in output on impact, but again this figure drops quite rapidly. Smets and Wouters (2007) also find that monetary-policy shocks account for relatively little of the variations in output and inflation in the US.

A bootstrap procedure was used to compute 90% error bands for the impulse responses. The results indicate that the effects of the shocks are statistically significant in the sense that the 90% bootstrap bands do not always cover zero. A range of robustness checks are reported in DPSS, including the use of the Hodrick–Prescott (HP) filter to measure output deviations and cutting off international linkages, either directly through the variables or indirectly through the covariance matrix.

4.5 Conclusion

This chapter shows that it is possible to estimate, solve, and simulate a forward-looking multi-country new-Keynesian model and use it to estimate the effects of identified supply, demand, and monetary-policy shocks. In constructing such a model it is necessary to be cautious with regard to the assumptions made about exchange rates, particularly the treatment of the numeraire, and the patterns of cross-country error spillover effects. To obtain theory-consistent results, it is also important that a priori sign and stability restrictions predicted by the theory are imposed on the parameters of the country-specific models. For all the economies considered, the qualitative effects of demand and supply shocks are as predicted by the theory. Monetary policy shocks are offset more quickly than is typically obtained in the literature. Global supply and demand shocks are the most important drivers of output, inflation, and interest rates in the long run. By contrast, monetary or exchange-rate shocks have only a short-run role in the evolution of the world economy. Despite the uniformity of the specifications assumed across countries, there are major differences between countries in the size of the effects of the shocks. Changing the degree of international transmission, through the use of alternative covariance matrices and foreign variables in equations changed the estimated size of the effects of the shocks. The results indicate the importance of international connections, directly as well as indirectly, through error spillover effects: a US monetary policy shock has effects on output and inflation in other countries that are of the same order of magnitude as its effects on the US. Ignoring global interconnections as country-specific models do, could give rise to misleading conclusions.

It is striking that using GVAR deviations and allowing for direct foreign linkages in the country-specific models produces sensible results. Either using HP deviations or cutting off direct linkages causes the results to become much less sensible. With HP deviations, adjustment is much slower and it is not clear that all the variables converge back to steady state after a shock. Without direct foreign linkages, the effects of the shocks do not match the theory.

While the MCNK model allows for considerable parameter heterogeneity, it might be thought unlikely that the augmented three-equation NK model applies to all 33 countries in the sample, with their very different economic structures and policy regimes. Similarly, one may be sceptical about whether the parameters are structurally stable. The estimation period ends in 2007, since subsequent events, in particular hitting the zero lower bound for interest rates, may have caused breaks in the relationships for some countries in the sample. The greater flexibility of the GVAR with more variables and fewer restrictions may allow it to represent variation over countries and time more effectively than a more restricted structural model like the MCNK. However, the MCNK model does provides a theoretically coherent and empirically viable framework for a range of extensions, such as the inclusion of more global and financial variables.

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5

External shocks and international inflation linkages

Alessandro Galesi and Marco J. Lombardi

Amid the recent commodity price gyrations, policymakers have become increasingly concerned in assessing to what extent oil and food price shocks transmit to the inflationary outlook and the real economy. In this chapter, we tackle this issue by means of a GVAR model. We first examine the short-run inflationary effects of oil and food price shocks on a given set of countries. Secondly, we assess the importance of inflation linkages among countries, by disentangling the geographical sources of inflationary pressures for each region. Results show that the direct inflationary effects of oil price shocks affect mostly developed countries, while less sizeable effects are observed for emerging economies. Food price increases also have significative inflationary direct effects, but especially for emerging economies. Moreover, significant second-round effects are observed in some countries. And finally, considerable linkages through which inflationary pressures spill over exist among regions. In addition, a considerable part of the observed increases in headline inflation is attributable to foreign sources for the vast majority of the regions.

5.1 Introduction

Increasing economic integration is at the current juncture raising a number of important issues concerning its potential implications. In particular, the majority of the world economies are observing a considerable degree of vulnerability to external shocks originating from sources that are often outside the economic sphere. For example, geopolitical tensions in oil-exporting countries could disrupt oil facilities and output, hence generating a surge in global energy prices. Nonetheless, even though the sources of these shocks are heterogeneous, their effects are timely reflected on the macroeconomic performance of affected countries. These macroeconomic effects could be generalized to the world economy—for example, when a supply shock in a local market implies large gyrations on international commodity prices—or they could spread 'by contagion' through transmission channels that are not immediately identifiable.

Monetary authorities are devoting special attention to the inflationary effects of external shocks. In this chapter we tackle the issue of international inflationary spillovers by estimating a Global VAR (GVAR) model, as introduced by Pesaran, Schuermann, and Weiner (2004) and further developed in Dées, di Mauro, Pesaran, and Smith (2007). Each of the countries under scrutiny is modeled as a vector autoregressive model augmented by weakly exogenous $I(1)$ variables, in which the endogenous variables are: core inflation, headline inflation, industrial production, nominal short-term interest rate, and nominal effective exchange rate. The global variables, i.e. the variables common to each model, are oil and food prices.

As a first exercise, we examine the effects of two exogenous shocks to food and oil prices on a set of macroeconomic variables of both developed and emerging economies. The main questions we tackle in this exercise are:

- Do the two shocks have different inflationary impacts?
- Is there a significant pass-through of external shocks to core inflation?
- To what extent are inflationary effects persistent?

We then evaluate the international linkages among countries and regions by simulating an increase in headline inflation in each region and then by decomposing the forecast error variances of each simulated shock into its respective source regions. The issues to be addressed in the following exercise are:

- Which are the main transmission channels of inflationary shocks across countries?
- Which regions are mostly affected by inflationary developments in other regions?
- How much of the inflationary innovations in a given region are accounted for by both domestic and foreign innovations?

5.2 External shocks and monetary policy

A typical external shock is an increase in oil prices. Given that crude oil is exchanged in a world-integrated market, most of the countries are in fact unable to individually influence its price. In the short run, oil price shocks affect macroeconomic performance through various channels, namely through their effects on real income, production costs, and uncertainty. In addition, if oil price changes are perceived as persistent, the affected economies would experience a significant structural modification of demand and supply of oil-based products. The main channels through which rising oil prices affect a given economy are:

- *Terms-of-trade effect*. This consists of a redistribution of real income from oil-importing countries to oil-exporting countries, since the terms of trade of the former decrease while those of the latter increase. The aggregate demand of the oil-consumer countries is expected to decline while the opposite is expected in the case of oil-producing countries.
- *Higher costs of production*. Since oil is a production factor, a price increase will raise the costs of production, while in the medium–long term there could be a substitution of oil with cheaper energy inputs.
- *Inflationary effect*. Since oil-based products are an important component of the consumer price index, the first-round effect of higher oil prices is a sudden increase of the headline inflation. The degree of pass-through into domestic prices depends on the domestic response to the shock.
- *Financial effect*. Since financial markets react quickly to changes in core macroeconomic variables, equity prices, bond ratings, and exchange rates would also be influenced from a rise in oil prices.
- *Psychological effect*. Given the uncertainty about how long oil prices will remain high, oil consumers could postpone their purchases of oil-related products (e.g. cars), or reduce their oil consumption.

The vast majority of the empirical literature on the macroeconomic impacts of oil price shocks is concerned with their real effects. Among others, Hamilton (1983, 1996) argues that almost all post-WWII US recessions have been preceded by oil price shocks. On the other hand, Barsky and Kilian (2001) suggest that oil price increases did not cause the stagflation of the 1970s. Kilian (2009) also challenges the common lore that oil price increases in the 1970s have been caused by supply-side shocks. From a more structural perspective, Kim and Loungani (1992) first examined the issue in a RBC setting, and Carlstrom and Fuerst (2006) extended their analysis into a DSGE model with monetary policy.

However, there also exists a strand of literature that focuses on the relationship between oil price changes and the rate of inflation. In general it is difficult to quantify the net inflationary effect of an oil price increase, given the various channels through which oil price shocks affect the economy. The pass-through of oil price changes into the domestic rate of inflation can be disentangled into three channels: (i) the direct or first-round effect, which refers to the rise in prices of energy products; (ii) the indirect effect, which refers to the pass-through of higher energy-related costs of production to prices of other goods and services such as freight and transportation; and (iii) the second-round effect, which refers to a situation where, due to an increase in the costs of living, workers demand a wage increase in order to maintain their real income.[1] While the effects of the first two channels are likely to be short in the medium term, the second-round effect is likely to be more prolonged and may result in a wage-price spiral, causing inflation to accelerate.

The work of Hooker (2002) is one of the main studies on the relationship between oil price changes and inflation. He uses a model including the rate of change of oil prices, the unemployment gap, and lagged inflation. Using a sample that spanned from 1962 to 2000, he found a structural break in the relationship between oil prices and inflation near the year 1980. By analysing separately the two subsamples 1962–80 and 1980–2000, he concludes that in the first subsample oil prices had a significant effect on inflation, while in the second subsample this effect has decreased. Trehan (2005) suggests that this could be due to a different monetary policy response since the lesson of the 1970s.

Looking at the monetary policy reaction to oil price shocks, after the oil price shocks of the 1970s, monetary authorities often adopted expansionary monetary policies, which eventually aggravated the effects on inflation (Bruno and Sachs, 1985). Using a VAR framework, Bernanke, Gertler, and Watson (1997) suggest indeed that oil price shocks induce a monetary policy response that can amplify its recessionary effects. Nowadays, most of the monetary authorities commit themselves to rapidly counter-inflationary pressures: monetary policy credibility is a fundamental determinant of the extent of second-round effects. A credible inflation-countering strategy would create a stable environment of low inflation, anchoring the inflation expectations, and thus influencing the price-setting behaviour. By focusing on the relationship between oil price shocks and core inflation in the US, Clarida, Galì, and Gertler (2000) show that nowadays the Federal Reserve counters inflationary pressures more aggressively than during the 1970s; this implies that inflation expectations are better anchored than during the 1970s. Therefore, given an oil price increase, inflation expectations would respond less than during the 1970s; hence monetary authorities would not need to undertake tightening measures as during the 1980s. Indeed, there is scant evidence that the recent sharp rise in energy prices has had significant second-round effects in industrialized countries.

[1] There is no consensus among monetary authorities about the definition of first- and second-round effects: the ECB and several other central banks consider the indirect effect as part of the first-round effect, while the Federal Reserve subsumes it under the second-round effect.

5.3 The GVAR model

To address the issues raised above, we build a GVAR covering 33 countries, both developed and emerging economies (cf. Table 5.1), and employ monthly data for the period 1999–2007. Each country model includes five country-specific variables: core inflation, headline inflation, industrial production, short-term interest rate, and nominal effective exchange rate. Due to data limitations, some country models do not include the whole set of country-specific variables: core inflation is not included in China, India, and Saudi Arabia's models, and industrial production is missing in the model of Saudi Arabia.

The foreign-specific variables, which serve as proxy for the influence of the rest of the world on a given economy, are calculated as weighted averages of the corresponding variables of other countries, with weights based on bilateral trade flows. The choice of weights based on trade is undertaken with the rationale that exogenous shocks, specifically adverse oil and food price shocks, could pass through on inflation in all countries via the trade channel. Specifically, weights are fixed over time, and computed as averages of exports and imports' cross-country data for the period 1999–2007.

Two global variables are considered: oil and food prices. Global variables are included in the US model as endogenous variables and in other country models as weakly exogenous. The choice of modelling the US differently is a tentative solution to take into account of their relative importance. Imposing the small, open-economy assumption to the US does not easily reconcile with empirical evidence; we therefore thought it appropriate to consider global variables as endogenous for this economy.

Table 5.1. Countries and regions in the GVAR model.

US	**Other developed European countries**	**South-eastern European countries**
	Denmark	Bulgaria
UK	Norway	Romania
	Sweden	
Euro area	Switzerland	**Emerging European countries**
Austria		Russia
Belgium	**Baltic countries**	Turkey
Finland	Estonia	Ukraine
France	Latvia	
Germany	Lithuania	**Developing Asian countries**
Greece		China
Ireland	**Central-eastern European countries**	India
Italy	Czech Republic	
Netherlands	Hungary	**Middle-eastern countries**
Portugal	Poland	Saudi Arabia
Slovenia	Slovak Republic	
Spain		

Each country model is individually estimated using monthly data over the period January 1999 to December 2007, treating the foreign-specific and global variables as weakly exogenous variables integrated of order one. The 12 euro-area countries are modelled as a single region as in Dées, di Mauro, Pesaran, and Smith (2007), while the remaining countries are estimated individually. After having estimated all the country models, their corresponding estimates are related through link matrices and then stacked together in order to build the GVAR model.[2] Finally, although estimation is at the country level, we analyse regional responses to both global and region-specific shocks, by aggregating GIRFs and GFEVDs using the averages of country PPP-GDPs over the period 1999–2007.

5.4 External shocks

By employing the GVAR methodology, we can provide evidence of the extent to which variables of each region in the GVAR move with the common external shocks, namely oil and food prices hikes. The analysis hinges on the generalized impulse response functions (GIRFs), proposed in Koop, Pesaran, and Potter (1996) and Pesaran and Shin (1998). The GIRFs assess the effects of observable-specific rather than identified shock, so it is not possible to give a structural interpretation of the shocks. Having this limitation in mind, we concentrate the analysis in providing evidence on the historical correlations between external shocks (shocks to oil and food prices) and the inflationary pressures across countries.

The GIRFs show the dynamic response of each domestic variable of each region to the simulated rises of oil and food prices up to a limit of 24 periods (i.e. two years). Confidence intervals are at the 90% significance level, and they are calculated via parametric bootstrap with 1000 replications.

5.4.1 *Oil price shock*

A positive standard error unit shock to nominal oil prices corresponds to an increase of about 6% of the oil price index in one month (cf. Figure 5.1). The food price response does not significantly vary, remaining close to the zero line.[3]

[2] Details of the integration properties of the series and the estimation procedure can be found in Galesi and Lombardi (2009).

[3] As we expected to observe a significant positive dynamic correlation between oil and food prices, this counterintuitive finding could be due to endogenizing the global variables in the GVAR model, so that the effect on food price of an oil price shock is dampened by all the variables' contributions in the system.

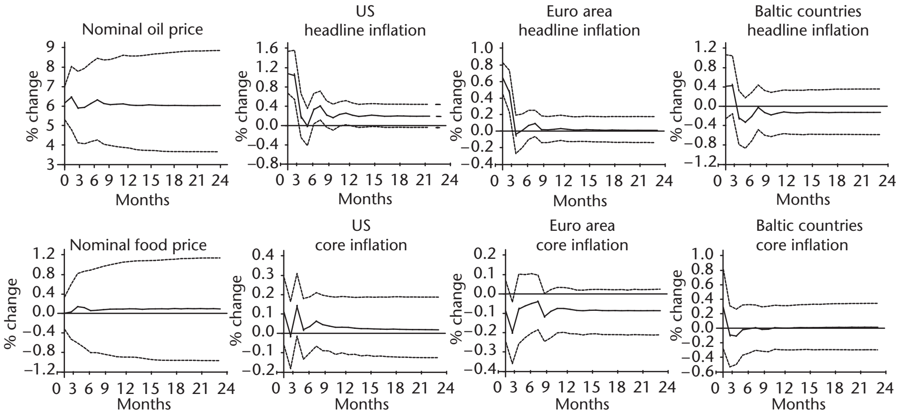

Figure 5.1. Generalized impulse responses of a positive unit (1 s.e.) shock to oil prices.

The impulse responses associated to the regional headline inflations provide the (non-structural) assessment of direct inflationary effects due to the oil price hikes. Overall, results indicate a significant historical correlation between oil price shocks and inflationary pressures for the developed regions under study, while non-significant effects are observed for less developed economies.[4] US headline inflation response (Figure 5.1) is on impact equal to 1.1%, then it rapidly dies out, becoming statistically non-significant after three months. Euro-area headline inflation (Figure 5.1) increases by 0.6% at the time of the shock, then its magnitude declines and reaches the baseline after two months. The observed effects on the euro area are nearly half of the size of the effects for the US: this could suggest that the euro area, while still strongly dependent on crude oil, has experienced, since the beginning of the 1980s, a steady substitution of oil towards cheaper energy sources, while the same does not hold for the US. Further, higher energy taxes in the euro area, rather than in the US, potentially explain this discrepancy, dampening the effect of oil price hikes.

The effects on core inflation are not statistically significant for the US (Figure 5.1); this is consistent with the findings in Hooker (2002). No second-round effects are found also for the euro area: given that both the FED and the ECB are particularly concerned by the nominal consequences of oil shocks, the following results suggest that also in this case the monetary policy framework contributes to anchoring inflation expectations at low levels.

[4] See Galesi and Lombardi (2009) for the full set of results.

5.4.2 *Food price shock*

A positive standard error unit shock to nominal food prices corresponds to an increase of about 1.8% in one month of the food price index (cf. Figure 5.2). The simulated food price increase is accompanied by a contemporaneous oil price increase, even though oil price response is not statistically significant.

A significant increase in headline inflation is found for Baltic countries, in which inflationary effects are persistent over time: the initial effect averages 0.5%, and then stabilizes after two years to 0.6% above the pre-shock level. In Galesi and Lombardi (2009), we show that the short-run inflationary effects for the remaining regions are mainly non-significant, even though they are in absolute terms bigger for emerging countries. The effect of a food price shock partially reflects the weight that the food price component has in each region-specific consumer price basket. As expected, since food is a relevant component of the CPI, especially for emerging economies, a food price shock mainly affects these regions.

US core inflation is significantly and positively affected by the food price shock (Figure 5.2): while on impact its response is not significant (and equal to a 0.1% increase), it becomes statistically significant after 5 months from the shock, then it increases stabilizing to 0.15% above the pre-shock level. The fact that a food price shock does not affect US headline inflation but core inflation suggests that increases in food commodities typically pass through into the domestic CPI with a substantial delay. Stronger effects are observed for the Baltic countries, where core inflation initially rises by 0.3%, then it averages a 0.4% increase after two years.

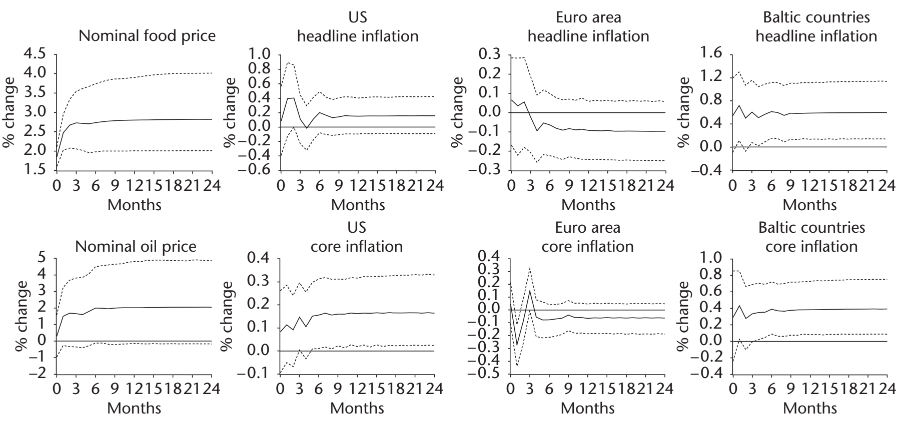

Figure 5.2. Generalized impulse responses of a positive unit (1 s.e.) shock to food prices.

5.5 International inflation linkages

As a second exercise, the generalized forecast error variance decompositions (GFEVDs) are calculated to assess how individual variables explain the geographical propagation of inflation.[5] In doing so, we provide insights on the international transmission channels of inflation.

Tables (5.2) and (5.3) report the results respectively for the US and the euro area. The headline inflation is itself the domestic variable that mostly explains the forecast error variance of the historical shock. While the relative importance of headline inflation decreases steadily over time for both the economies, the contribution of core inflation remains stable for the euro area, while it tends to gain importance over longer horizons for the US. This result implies that a component of the headline inflation increase feeds into the core inflation, thus becoming more persistent over time. The relative contribution of the US nominal short-term interest rate is negligible: it is on impact equal to 0.2%, then it increases to 0.4% after two years; in contrast, due to a shock to the euro area headline inflation, the nominal short-term interest rate explains 3.5% of the shock on impact, then its contribution decreases over time, reaching 0.8% after one year. While it is not possible from these results to infer anything about the reaction functions

Table 5.2. Generalized forecast error-variance decompositions: a positive standard-error unit shock to US headline inflation.

Months	0	1	2	4	8	12	24
US variables							
Core inflation	0.7	2.0	2.2	2.5	3.5	4.0	4.8
Headline inflation	37.1	35.1	34.0	34.4	34.2	33.9	32.7
Short-term interest rate	0.1	0.1	0.1	0.3	0.3	0.3	0.4
Exchange rate	0.1	0.1	0.9	1.6	1.4	1.4	1.4
Industrial production	19.5	24.0	24.4	24.3	25.5	26.2	27.8
	57.4	61.3	61.6	63.1	65.0	65.9	67.1
Foreign variables							
Food price	0.0	0.0	0.0	0.1	0.1	0.1	0.2
Oil price	7.4	4.8	3.3	2.6	2.1	1.9	1.7
euro area	12.3	10.8	11.2	10.7	10.1	9.7	8.8
UK	3.0	3.1	3.1	3.1	3.1	3.2	3.4
Other developed European countries	6.6	6.3	6.6	6.2	5.6	5.2	4.5
Baltic countries	3.4	3.4	3.7	3.9	3.7	3.7	3.6
Central-eastern European countries	4.1	4.0	4.1	3.9	3.6	3.4	3.3
South-eastern European countries	1.3	1.5	1.6	1.7	1.8	1.8	2.0
Emerging European countries	0.7	0.7	1.0	1.2	1.3	1.4	1.5
Developing Asian countries	2.9	3.1	2.7	2.4	2.2	2.1	1.9
	42.6	38.7	38.4	36.9	35.0	34.1	32.9

[5] For better readability, we scale the GFEVDs to a hundred, as in Wang (2002).

Table 5.3. Generalized forecast error-variance decompositions: a positive standard-error unit shock to euro-area headline inflation.

Months	0	1	2	4	8	12	24
Euro area variables							
Core inflation	9.3	8.5	7.1	7.0	7.6	8.1	8.9
Headline inflation	34.7	28.4	26.2	25.2	23.5	22.1	18.7
Short-term interest rate	3.5	3.8	2.7	1.5	0.9	0.8	0.7
Exchange rate	1.2	5.1	6.7	8.1	9.6	10.4	11.8
Industrial production	4.8	4.2	4.0	3.5	3.1	2.8	2.2
	53.6	50.0	46.7	45.5	44.8	44.1	42.3
Foreign variables							
Food price	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Oil price	0.4	0.2	0.2	0.2	0.1	0.1	0.1
US	12.7	13.3	13.6	13.9	14.2	14.4	14.7
UK	3.2	4.2	4.7	5.0	5.3	5.5	6.1
Other developed European countries	8.8	8.7	9.2	9.0	8.8	8.6	8.2
Baltic countries	6.4	6.5	6.6	6.6	6.5	6.5	6.5
Central-eastern European countries	3.0	3.2	3.9	4.2	3.7	3.6	3.4
South-eastern European countries	3.2	3.5	3.6	3.9	4.4	4.8	5.4
Emerging European countries	3.2	3.1	3.1	3.1	3.0	3.0	3.1
Developing Asian countries	4.3	5.1	5.5	5.9	6.2	6.5	7.0
Middle-eastern countries	1.2	2.2	2.5	2.6	2.7	2.8	3.0
	46.4	50.0	53.3	54.5	55.2	55.9	57.7

of the different monetary authorities, we can nonetheless observe that the contribution of the interest rate is markedly different among the two regions (small and increasing over time for the US, larger and shrinking in time for the euro area).

The relative importance of exchange rate innovations tends to increase over time. On impact, the US nominal effective exchange rate's contribution is not relevant, it slightly increases over time, passing from 0.1% on impact to 1.4% after two years. In the case of the euro area, the contribution of the exchange rate averages 1.2% on impact; as for the US, it increases, reaching 11.8% after two years. This result, joint with the decreasing importance of headline inflation over the forecast horizon, is in line with the finding of Eun and Jeong (1999) that inflation innovations tend to pass through to the domestic price levels faster than exchange rate innovations. This evidence suggests that exchange rate innovations may be perceived as less permanent, whereas the opposite may hold for headline inflation innovations. As the authors suggest, the underlying mechanism could be rationalized by firms that do not change their prices in a timely manner following fluctuations of exchange rates, but prefer to adjust their mark-ups, following a *pricing-to-market* strategy. This phenomenon implies that, in the short run, the exchange rate pass-through is incomplete.

Oil and food prices markedly differ in contributing to the hike in US inflation. The oil price explains 7.4% of the forecast error variance of the simulated shock to the US headline inflation on impact, 2.1% after one year and 1.9% after two years. Conversely, the price does not contribute, at all horizons, to the explanation of the simulated shock. Regarding the euro area, oil and food prices do not considerably explain the inflation rise. This is possibly due to the fact that oil and food price contributions feed into the headline inflation counterparts of all the regions, so that the global variables implicitly contribute through headline inflation innovations.

The foreign regions that mostly explain the rise of the US headline inflation on impact are the euro area (12.3%), the other developed European countries (6.6%), and the Central-eastern European countries (4.1%). The regional contributions vary over time, and after two years the euro area is still the foreign region that mostly explains the shock (8.8%). In the case of the euro area, on impact the most relevant foreign regions are, in decreasing order of importance, the US (14.7%), the other developed European countries (8.8%) and the Baltic countries (6.4%). After two years, these are still the US (16.2%), followed by the other developed European countries (8.2%) and the developing Asian countries (7.0%). Interestingly, regional contributions do not strictly follow an international trade pattern. We also remark that the regional contributions are not symmetric, in the sense that the geographical transmission channel is mainly unidirectional, from the larger to the smaller country.

Overall, domestic sources mostly explain on impact the inflationary shocks (57.4% and 53.6%, respectively, for the US and the euro area). For the US, the foreign contribution decreases over time, while the opposite holds for the euro area. Structural differences between the two economies (e.g. different degrees of trade openness) are potential candidates to explain this divergence, but apart from these, our GVAR is able to reveal the topical role of the exchange rate: in the euro area the importance of headline inflation decreases over time, while the opposite is observed for the effective exchange rate counterpart. As explained before, this phenomenon could imply an incomplete exchange rate pass-through in the short run.

5.6 Concluding remarks

This chapter covered the implementation of the GVAR methodology to study short-run inflationary effects of common external shocks as well as the international transmission of inflation for a set of 33 countries. Oil and food price shocks have different inflationary effects across regions. Results show that during the period 1999–2007, the inflationary effects of an oil price shock mostly affected developed regions, while food price increases hit particularly emerging economies. Further, no significant relationship between oil shocks and core inflation for the US and the euro area is observed. This may suggest that the presence of significant second-round effects on inflation depends on the country-specific reaction function of the monetary authorities. The GFEVDs reveal some interesting results: first, there exist considerable geographical linkages among regions through which inflationary pressures are transmitted; second, a considerable part of headline inflation changes in the vast majority of the considered regions is attributed to foreign sources.

It is important to keep in mind that these results are based on a non-structural model, so this analysis does not provide a thorough economic understanding of the linkages. The GVAR methodology is here exploited in providing empirical evidence, in terms of dynamic historical correlations among variables, of the international transmission of inflationary pressures. In this context, the potential of this methodology consists in dealing with the estimation and the dynamic analysis of a multi-country economy featuring a very large number of variables. The typical curse of dimensionality which affects standard modelling approaches would make this analysis unfeasible.

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6

International business cycles and the role of financial markets*

Sandra Eickmeier and Tim Ng

6.1 Introduction

Interest in how cross-border financial activity affects international economic dynamics has exploded since the global financial crisis of the late 2000s. Prior to then, most macroeconomic models used in central banks, and many of those in academia—even those focused on domestic dynamics—had typically not taken the financial sector very seriously, despite influential work in the 1990s such as Bernanke et al. (1999) and Kiyotaki and Moore (1997) on the contribution of financial frictions to business cycles. The crisis changed this situation markedly by making clear that financial shocks and financial markets deserve attention as sources and transmitters of international disturbances, alongside traditional trade channels. An example of the much richer treatment of banking and financial markets in recent DSGE models (albeit a closed-economy case) is Christiano et al. (2010).

This chapter summarizes our recent work (Eickmeier and Ng, 2011) on financial shocks and their international transmission using the GVAR approach (Pesaran et al., 2004). The GVAR is one of two recent approaches to modelling international dynamics with more than a few countries and variables, which can otherwise easily generate models so large as to be inestimable using standard econometric techniques. The other approach is the factor-augmented VAR (FAVAR; Bernanke et al., 2005). For our work, we favour the GVAR because it allows more explicit, rich, and flexible modelling of country-specific dynamics, which tend to be neglected in FAVARs. GVARs

* The views expressed in this chapter do not necessarily reflect the views of the Deutsche Bundesbank or the Reserve Bank of New Zealand.

also allow for co-integration, whereas factor methods generally require stationary variables and therefore discard potential long-run information.

Both GVARs and FAVARs reduce the number of parameters by constructing a small number of 'foreign' or 'rest of world' variables based on weighted averages of a (much) larger number of variables from individual foreign countries (in our case, financial as well as macroeconomic variables). Whereas FAVAR studies of international dynamics use statistical criteria based on the foreign country data itself to determine the weights (e.g. Eickmeier et al., 2011 and Helbling et al., 2011), the GVAR weighted averaging process uses additional information to determine the bilateral country exposures. The additional information is usually chosen on intuitive grounds. Earlier work on international business cycles, for example, has typically used trade exposures (e.g. Dées et al., 2007).

The GVAR approach of explicitly selecting weights based on additional information suits our purposes of exploring international financial shock transmission to many countries. As well as the usual output and inflation, our GVAR setup features financial variables such as interest rates, exchange rates, equity prices, corporate bond spreads, and credit for 26 economies. We are interested in using data on different types of international financial exposures for the bilateral country financial exposure weights, and compare different financial weighting schemes with each other and with the more typically used trade weighting scheme. We examine financial weighting schemes based alternatively on cross-border portfolio investment, direct investment, and banking exposures, which in principle could act differently as channels for foreign shocks. For example, direct investment features a greater degree of management control by the investor and a longer-term investment horizon compared to portfolio investment, which could mean weaker transmission of foreign shocks. Portfolio investments are also easier to liquidate than banking or direct investment exposures, which might imply faster cross-border transmission of foreign shocks to local asset prices.

We also distinguish asset-side (that is, outward financial investment) exposures from liability-side (inward investment) exposures. Asset-side exposures capture the risks of credit loss or valuation changes on foreign investments, and have featured in GVAR studies such as Beaton and Desroches (2011). Liability-side exposures include the risk of foreign investors withdrawing funding. Although there is a tradition of research on such risks, especially severe 'sudden stop' cases, there seems to be little GVAR work addressing this foreign shock transmission channel.

The weighting scheme for financial variables based on inward foreign direct investment exposures turns out to fit the data best, based on (in-sample) forecasting performance and information criteria. We choose this scheme for our benchmark model for the investigation of international shock transmission. The financial quantity and price variables featuring in the GVAR allow us to capture a range of potential cross-border financial transmission effects. These include market-mediated mechanisms such as arbitrage in international markets (e.g. Perri and Quadrini, 2011) and rebalancing of international portfolios when there are leverage constraints (e.g. Krugman (2008)'s 'international financial multiplier'), as well as institution-mediated mechanisms such as multinational financial institutions raising capital, reducing lending, or dumping illiquid assets in some countries to maintain global capital, and liquid asset ratios when faced with loan losses (e.g. Enders et al., 2011) or funding squeezes (Gorton, 2009) in other countries.

We focus on the international transmission of shocks that reduce the supply of credit to the private sector. These might result from unexpected changes in banks' or investors' financial condition (Gertler and Karadi 2011; Christiano et al., 2010), risk aversion (Gilchrist et al., 2009) or regulatory requirements (Gerali et al., 2010). Financial innovation (e.g. emergence of new securitization products or markets) could also be a source of (positive) credit supply shocks (e.g. Peersman, 2010 or Atta-Mensah and Dib 2008). Reflecting their roles as major international financial centres, we identify credit supply shocks originating in the US, the euro area, and Japan, and then trace their effects on other countries. This partly reflects the importance of advanced-country credit and funding markets in the recent global crisis (e.g. Cetorelli and Goldberg, 2011).

Unlike existing GVAR applications such as Galesi and Sgherri (2009), Xu (2010) and Chen et al. (2010), we identify credit supply shocks using sign restrictions (based on differing patterns of responses across variables to different types of shocks), and broaden the countries under consideration from the US to the euro area and Japan as shock source countries, and to many other individual countries as destinations. The rest of the chapter explains our study in more detail.

6.2 GVAR model specification and selection

We use the standard GVAR setup implemented in the toolbox provided by Vanessa Smith and Alessandro Galesi.[1] In our case, the modelled data consist of GDP, the real bilateral exchange rate against the US dollar, real equity prices, the oil price (all in logs), the first log-difference of the CPI, short- and long-term government bond yields, the long-term corporate bond spread,

[1] The GVAR toolbox can be downloaded from <http://sites.google.com/site/gvarmodelling/gvar-toolbox>.

and real domestic private credit to the non-financial private sector. We use a broad measure of credit, including debt securities as well as bank loans, because we are interested in the broad supply of credit to the economy. We use corporate bond yields rather than bank lending rates because corporate bonds are continuously traded, and because important characteristics of lending such as collateral, early repayment provisions, and 'relationship banking' components are more standardized (or absent) in corporate bonds. We collect these data (where available) for 33 countries,[2] including eight from the euro area, which we combine to form a euro-area aggregate because of the common euro-area monetary policy since 1999. This gives us 26 economies. The variety of financial variables is important both to cover international financial transmission channels in rich detail and to enable the identification of the credit supply shock as distinct from other types of shock.

Our sample runs from 1983q4, the start of the corporate bond data, to 2009q4.

Our variations on weighting schemes focus on the weights for the foreign financial variables. We compare seven schemes in total: one with trade weights for all variables (Trade), and six with trade weights for GDP and inflation and with financial weights based on inward or outward portfolio (PIin and PIout) or foreign direct investment (FDIin or FDIout), or banking claims (BCin or BCout) for the other variables (credit, interest rates and spreads, equity prices, and the exchange rate). Our financial weights are given by gross bilateral financial claims data on total portfolio equity and debt investment asset positions, total foreign direct investment asset positions, and consolidated international banking claims, in each sample country. We use the same bilateral asset data for asset-side and liability-side exposures, by simply reversing the direction of exposure (one country's bilateral asset-side exposure is the other country's liability-side exposure). All weights are fixed over time. Details of the data are in the paper.

In principle, we could allow the weighting schemes to vary by country and by variable, because of the possibility that the cross-border impacts of movements in different variables might be different and depend on the countries involved. However, with our 26 countries, up to seven foreign variables in each country VAR, and seven possible sources of bilateral weights for each foreign variable, this would imply an unmanageable number of possible schemes. We therefore constrain the type of financial exposure for determining the bilateral weights to be the same across financial variables and countries in each of our GVAR specifications.

[2] The countries are Argentina, Australia, Austria, Belgium, Brazil, Canada, China, Chile, Finland, France, Germany, India, Indonesia, Italy, Japan, Korea, Malaysia, Mexico, the Netherlands, Norway, New Zealand, Peru, the Philippines, South Africa, Saudi Arabia, Singapore, Spain, Sweden, Switzerland, Thailand, Turkey, the UK, and the US.

It should be noted that using a bilateral weight based on a particular type of financial exposure or on trade exposure does not mean that the only bilateral transmission channel captured by the weight is that associated with the chosen type of exposure. The true bilateral weight will reflect a combination of different channels between the two countries. It is an empirical question which of the types of financial or trade exposure produce a weight that best approximates the true weight.

We show in the paper that financial bilateral weights can be quite different from trade weights. For example, for Japan, financial exposures to the US and euro area are in general larger than trade exposures. For all countries or regions, the UK is more important as a source of financial exposure than of trade exposure. Asia (excluding Japan) is an important trading partner for almost all other regions, but much less important as a source of financial exposure.

All our country VAR models except the US model are set up for estimation with all the variables listed above except the oil price as endogenous, and foreign variables and the oil price as weakly exogenous. The US model does not include foreign interest rates, foreign equity prices, or foreign credit, because the US is assumed to be dominant in world financial markets. The US model also uses the US dollar effective exchange rate instead of a bilateral exchange rate, and includes the oil price as an endogenous variable. We estimate the country VAR models using the standard unit root and co-integration test procedures in the GVAR toolbox (details are in the paper).

The GVAR specification based on the FDIin weighting scheme produces the lowest root mean squared error (RMSE) on in-sample GDP forecasting for horizons up to four quarters ahead, and also performs well on the other variables. The specifications using financial weighting schemes all perform better than the specification using trade weights only. We also compare specifications using the Akaike and Schwarz information criteria, which correct for differences in the number of estimated parameters. The FDIin model comes in second best on these criteria, which take into account the fit for all variables. Because we are most interested in specifications that could forecast GDP well, we choose the FDIin scheme as our benchmark. The paper contains details of the estimation, forecasting performance, and information criteria results.

6.3 Credit supply shock identification and responses to shocks

For our study, we do not use the generalized impulse response function (GIRF; Koop et al., 1996; Pesaran and Shin, 1998) adopted in most GVAR applications. This is because GIRF involves shocks to the GVAR system that are not necessarily well-identified in the sense of having a clear economic interpretation. In our case, we are interested in the specific effects of shocks to credit supply, disentangled from the effects of other shocks that might be happening at the same time.

We identify credit supply shocks using sign restrictions on the short-run responses of the GVAR variables to the shock. This technique draws on theoretical models or reasoning to identify a shock through its effects on the other variables in the system. The sign-restriction approach has to date not been much used in GVAR models. The few exceptions include Chudik and Fratzscher (2011) and Bussière et al. (2011).

The identification of a negative credit supply shock involves the following theoretically motivated restrictions (summarized in Table 6.1), which are consistent with responses in DSGE models containing a banking sector (Hristov et al., 2011).

(1) After a negative credit supply shock, credit and GDP are required to fall for the first three quarters after the shock, and GDP to fall by less than credit on impact. The restriction that the credit to GDP ratio should fall on impact distinguishes credit shocks from 'macro shocks' such as aggregate demand and supply shocks, in response to which GDP should react more strongly on impact than credit.

(2) We restrict the corporate bond rate to increase on impact. In combination with the restriction on credit to fall, this restriction distinguishes credit supply shocks, which should move corporate bond rates and credit in opposite directions, from credit demand shocks, which would move them in the same direction.

(3) We restrict the spread between the corporate bond rate and the long-term government bond yield to increase on impact, to reflect that the credit risk premium should rise under an adverse credit supply shock.

(4) We restrict the spread between the corporate bond rate and the short-term interest rate to increase on impact, to distinguish the credit supply shock from a monetary policy (tightening) shock, which would tend to lower that spread. (The restriction on credit and GDP to fall should exclude monetary loosening shocks.)

We restrict the corporate bond rate and the spreads on impact only, to allow them to adjust rapidly to the shock subsequently. We do not restrict the responses of inflation and of the short-term interest rate at all, because the signs of the responses of those variables to a credit supply shock depend on whether aggregate demand or aggregate supply effects dominate and on the monetary policy reaction.

Table 6.1. Identifying restrictions for credit supply shocks.

Variable	y	Dp	credit	crspread	sr	lr	eq	ep	credit-y	cr	cr-sr
Restrictions	−		−	+					−	+	+
Lags	0–3		0–3	0					0	0	0

Notes: y: real GDP; Dp: inflation; credit: volume of credit; crspreads: corporate bond yield—10-year government bond yield; sr: short rate; lr: long-term government bond yield; eq: equity price; ep: exchange rate; cr: corporate bond yield computed as crspread+lr. The sign restrictions $-/+$ are implemented such that the impulse response is ≤ 0 or ≥ 0.

These restrictions are all applied to the responses of domestic variables (that is, variables in the country in which we are identifying the credit supply shock). This yields shocks that are uncorrelated with other domestic shocks, but that can still be correlated across countries.[3] However, we check that we can regard the identified credit supply shocks as essentially country-specific by looking at the cross-country residual correlations. Because the foreign variables enter the country VAR models contemporaneously, they are able to soak up contemporaneous cross-country correlation. We find that the absolute pairwise correlations between residuals across countries is 0.17 at most, and 0.04 on average. The correlations between the three identified credit supply shocks are very low, at −0.03 (US-euro area), 0.12 (US–Japan), and 0.08 (euro area–Japan).

Using the benchmark GVAR, we then examine the responses of the domestic variables (Figure 6.1) and selected variables in other countries (Figures 6.2a–e) to one standard deviation negative credit supply shocks in the US, the euro area, and Japan.[4] The domestic decline of credit in response to the shock is persistent in all three economies, and substantially stronger in the euro area (about 3%, median estimate) than in Japan (1%) and in the US (0.6%). The positive response of credit spreads is long-lasting in the US, but turns insignificant after one quarter in the euro area and Japan.

In all three economies, the credit supply shocks reduce domestic GDP significantly, with the largest response in Japan (about 0.4%), followed by the US (−0.3%) and the euro area (−0.2%). The GDP response is persistent in the US and Japan but not in the euro area.

Mechanisms contributing to the credit supply shock's overall impact on domestic GDP do not appear to be the same for each economy. A decline in

[3] Dées et al. (2007) identified a US monetary policy shock similarly, using recursive identification within the US block but leaving the US shocks correlated with shocks in other countries. Dées et al. (2010) also identified shocks that are uncorrelated within, but not across, countries.

[4] Figure 6.1 shows median responses and 90% confidence intervals from a bootstrap. For reasons of space, Figure 6.2 shows median responses only, and both figures show selected variables and regions only. See the paper for full details and charts of all variables and regions, and confidence intervals for the foreign responses.

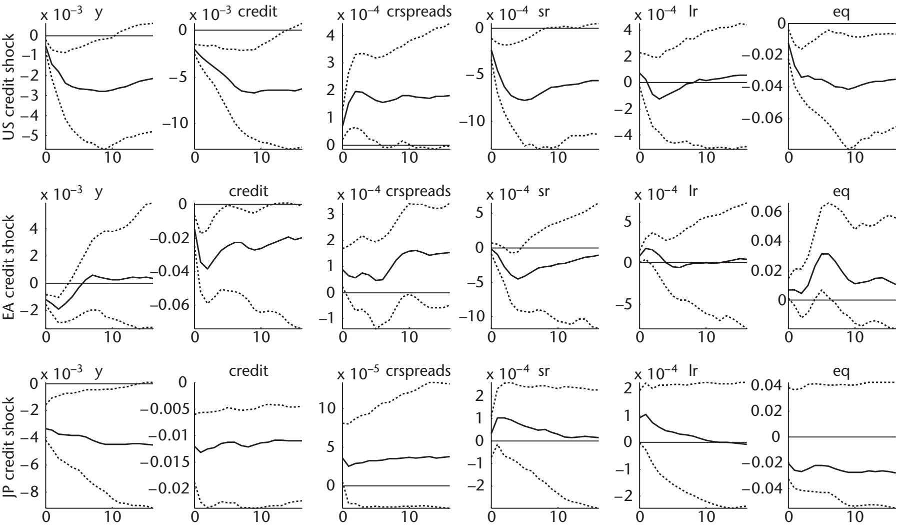

Figure 6.1. Domestic transmission of credit supply shocks (benchmark model FDIin).

domestic equity prices plays a much bigger role in the US, perhaps reflecting generalized confidence effects or the impact of collateral values on bank lending. Also, the US dollar appreciates significantly against most other currencies in response to the US credit supply shock (Figure 6.2e), whereas the euro and the yen depreciate in response to credit supply shocks in those economies, thus cushioning the negative impact of the shocks on GDP. Third currencies also depreciate to some extent against the US dollar in response to the euro-area and Japanese shocks. Another way of putting it is that the US dollar uniformly appreciates in response to shocks from any of the three financial centres, suggesting that such shocks generate a strong 'flight to safety' response towards the US dollar in foreign exchange markets. Finally, the adverse impact of the US credit supply shock on GDP in other countries is generally larger than that of the shocks to the other two centres, which would suggest a stronger feedback (via trade, for example) to US GDP. The domestic GDP impact of the US credit supply shock is cushioned partially by a monetary policy loosening, which features in the domestic response to the euro-area shock also but not in that to the Japanese shock, possibly because the zero lower bound for interest rates was binding over most of the sample period for Japan. The responses of domestic inflation (which we do not restrict) to the credit supply shocks are generally not significant apart from on impact (not shown).

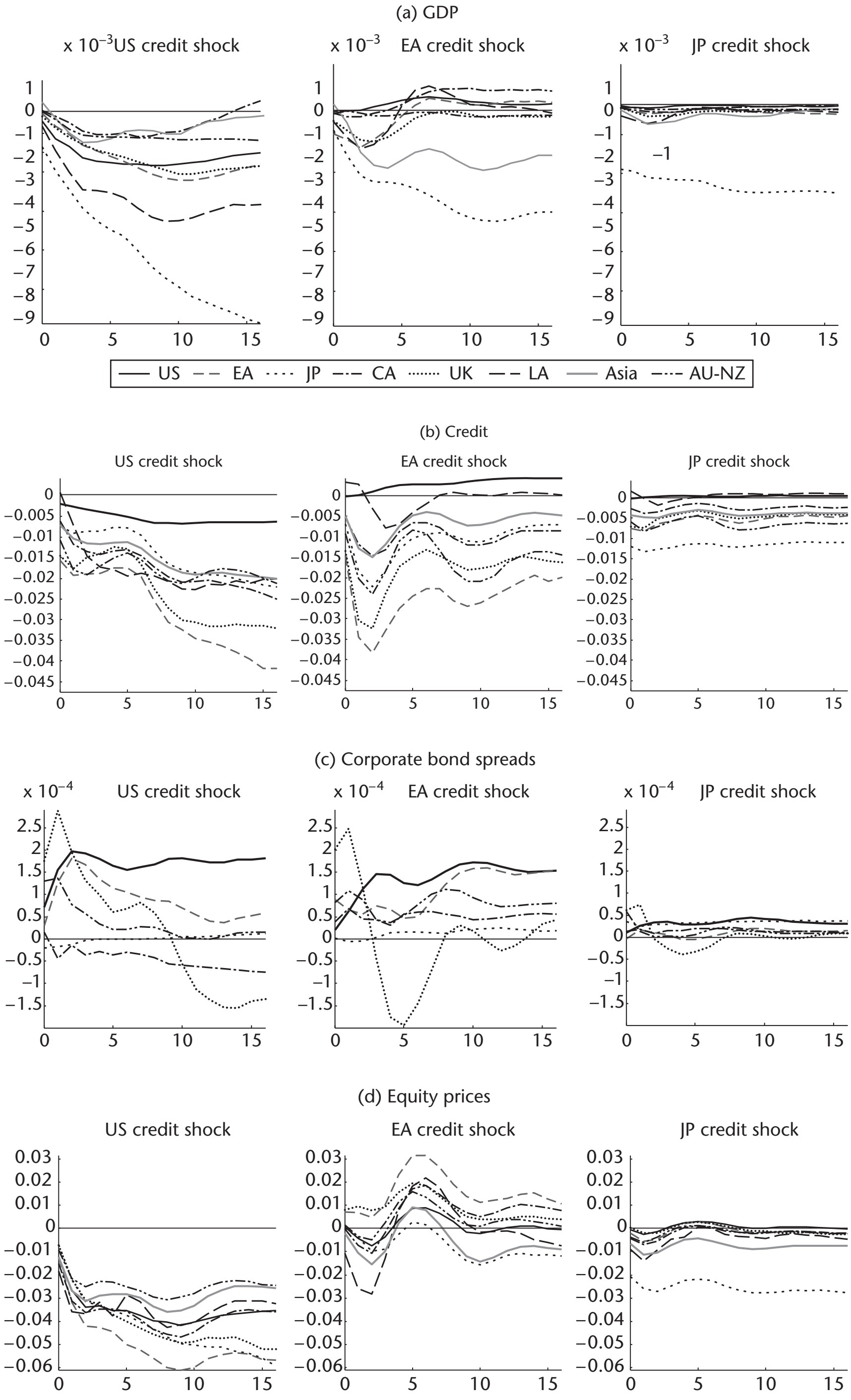

Figure 6.2. Median impulse responses for selected countries/regions and variables to foreign credit supply shocks (benchmark model FDIin). (a) GDP; (b) Credit; (c) Corporate bond spreads; (d) Equity prices; (e) Exchange rates (against the US dollar).

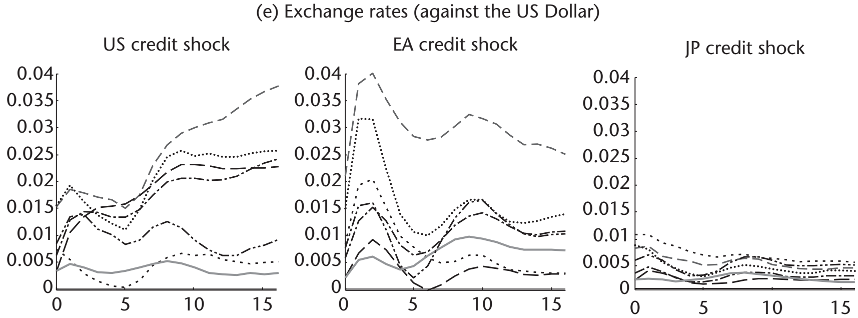

Figure 6.2. Continued

Looking at the cross-border effects, we find that the US credit supply shock has a strong and significant impact on GDP in Japan especially, and weaker effects on other regions.[5] The cross-border effects of the US shock on Japan, the euro area, the UK, and Latin America are about as large as on the US itself, which seems roughly consistent with output co-movements during the crisis (van Wincoop 2011), and consistent with the empirical findings of Helbling et al. (2011) and Eickmeier et al. (2011). The effects on the other regions are insignificant.

GDP declines significantly in Japan and the UK in response to the euro-area shock. The Japanese credit supply shock has a significant negative effect on GDP only in the UK. As with the US shock, the euro-area shock has effects on GDP in Japan and the UK at least as large as the effect on domestic GDP. By contrast, the Japanese shock has its largest effects on Japanese GDP. In general, the cross-border effects of the euro-area and Japanese shocks are weaker than those of the US shock.

The results suggest clearly that foreign credit and financial markets are involved in the international transmission of credit supply shocks, especially those emanating from the US. The US credit supply shock leads to strong and significant declines in credit (Figure 6.2b) in most other countries or regions. Credit in most regions also declines in response to euro-area and Japanese credit supply shocks. Corporate bond spreads (Figure 6.2c) in the US, UK, and Australia–New Zealand increase significantly in response to credit supply shocks in all three financial centres. Interestingly, corporate bond spreads in the euro area and Japan respond only very briefly. This may reflect the greater development of the US, UK, and Australian corporate bond markets compared to those in the other regions (Borio, 1995). (Corporate bond spreads for the Latin American and Asian countries are

[5] Impulse responses for the aggregates are constructed by weighting impulse responses of individual countries together using their PPP-adjusted GDPs, averaged over 2006–08.

missing in our sample.) All equity prices decline in response to the US shock (Figure 6.2d), but none responds to the euro-area and Japanese shocks. Monetary policy in many foreign countries loosens following the US shock (not shown).

We look at the difference that varying the foreign-variables weighting scheme from the benchmark makes to the impulse response results. The responses are similar in terms of shape, sign, and magnitude, and the confidence bands around the responses under the different specifications generally overlap. We also compare the impulse response results from our benchmark GVAR with those based on a sample shortened to end in 2007q2, to exclude the global financial crisis. We find very similar results, suggesting that the crisis episode is not unduly influencing them.

Finally, we assess how important the three credit supply shocks are for international business cycles in nine countries or regions, by calculating the forecast error variance (FEV) shares for GDP explained by the shocks. We find that US credit supply shocks explain a substantial proportion—a quarter—of GDP FEV in the US itself, and up to a quarter of the GDP FEV in foreign countries, at a horizon of four years. The shares of FEV explained by the US shock are particularly large for Japan, Latin America, and Europe, but smaller for Asia and Canada. The small share of Canadian GDP FEV explained by US credit supply shocks is interesting given Canada's large trade with the US, but is consistent with the Canadian financial system's reputation for stability (e.g. Bordo et al., 1994). The shares of euro-area and Japanese GDP FEV explained by the respective domestic credit supply shocks are similar to the US case at a shorter horizon of one year, but considerably smaller at the longer horizon. The shares of foreign output FEV explained are much smaller, at less than 10 and 5%, respectively.

6.4 Conclusion

In this chapter, we summarize our recent work looking at the international transmission of credit supply shocks using the GVAR. The GVAR framework is a useful and flexible tool to address our questions. Using different bilateral weighting schemes reflecting countries' bilateral exposures to each other via trade and finance, we are able to explore how weights based alternatively on portfolio investment, direct investment, and banking claims, and both asset- and liability-side channels, affect the fit of the GVAR to the data. We find that using financial weights based on inward FDI exposures for financial variables and trade weights for output and inflation fit the data best out of the alternative financial weighting schemes assessed, and substantially better than a scheme based on trade weights only. We view this assessment of alternative assumptions regarding the weighting schemes as an important validation step in GVAR modelling, that we seldom see reported in other GVAR studies. Although weights may not matter asymptotically, in practice (with finite samples) they can matter, and it is therefore important to choose the weighting scheme carefully. The results on model fit confirm the importance of considering cross-border financial exposures as well as trade exposures when modelling dynamics involving many countries.

Using the benchmark GVAR chosen on the basis of the fit results, we study in considerable country-level detail the domestic and cross-border effects of credit supply shocks originating in the US, euro area, and Japan, three major international financial centres. Our main results do not change much when we exclude the 2007–09 crisis episode from the sample. We find that US credit supply shocks propagate to output, credit, and financial markets in other countries strongly, while the transmission of euro-area and Japanese credit supply shocks is weaker. The US credit supply shock seems to propagate via a clear 'international financial multiplier', which is less evident for the shocks to the other two financial centres. The responses of foreign credit and financial markets after the US shocks suggest balance sheet, arbitrage, and portfolio reallocation effects, and perhaps expectational effects related to the US financial markets' role as a global bellwether. We also find strong exchange rate responses consistent with flight-to-quality towards the US dollar, in response to shocks from all three economies.

It is notable that the UK, which is also an international financial centre, generally shows significant responses to all three credit supply shocks, whereas emerging market economies in Latin America, other Europe and Asia tend not to show much significant response. The latter countries are generally less internationally financially integrated (Lane and Milesi-Ferretti 2007), which supports the idea that the strength of financial linkages is important to the cross-border transmission of credit supply shocks from international financial centres.

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7

Using global VAR models for scenario-based forecasting and policy analysis

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7.1 Introduction

GVAR models have been widely applied to the analysis and evaluation of policy-relevant counterfactual exercises. The majority of existing applications have employed generalized impulse response functions to evaluate the macroeconomic and/or financial impact of shocks in the error processes of individual equations in the GVAR system. In this chapter, we will demonstrate how GVAR models can be used to evaluate more complex scenarios, both through probabilistic forecasting and by working with linear combinations of impulse responses. In so doing, we will draw heavily upon a recent paper in which we extend the GVAR model pioneered by Pesaran, Schuermann, and Weiner (2004) and Dées, di Mauro, Pesaran, and Smith (2007, DdPS) to investigate the issue of global imbalances (Greenwood-Nimmo, Nguyen, and Shin, 2012, henceforth GNS). It follows that GVAR is a uniquely powerful tool for the analysis of global imbalances as it provides a truly global framework within which to assess the effects on a sovereign state, on an economic bloc, or even on the world economy of both global shocks and of shocks emanating from specific countries or regions (Bussière

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et al., 2009).[1] Efforts to analyse the causes and forecast the development of these imbalances are clearly of paramount importance in an increasingly globalized world economy.

In GNS, we extend the DdPS model to include both real export and real import series, and also to account for country-specific structural breaks following Shin (2009). This extended model is then used as a basis on which to conduct a range of scenario-based probabilistic forecasting exercises. Probabilistic forecasting involves computing the conditional probability that a given event or scenario will occur over a defined horizon by means of model-based simulations. GVAR models are particularly well suited to such applications due to the potentially large number of variables in the system, which allows the forecaster to consider a wide variety of interesting and policy-relevant scenarios. Moreover, in the case of the GNS model, directional analysis indicates that its forecasting performance is generally very good, particularly at longer horizons, where the global linkages embedded in the model give it a decisive advantage over the benchmark random walk and AR models.[2]

The GNS model is estimated using a data set with the same geographic coverage as DdPS and Dées, Holly, Pesaran, and Smith (2007, DHPS), which spans the period 1980q2–2007q2. The resulting central and interval forecasts are generally consistent with subsequent experience of the global financial crisis. The model predicts a marked economic retrenchment and stock market slump coupled with non-negligible inflationary pressure in the group of four focus countries studied in GNS (the US, the Eurozone, Japan, and China). This is naturally also reflected in probabilistic forecasting exercises, which indicate a very low probability of the central banks in these focus countries meeting their output and inflation goals after 2008. More interesting, however, is our analysis of balance-of-trade scenarios, which provides an intuitive four-way classificatory system. In the three years up to mid-2010, our forecasts suggest a high probability of a balancing improvement in the US trade deficit and also of an unbalancing improvement in the Chinese surplus.[3] Moreover, our results indicate a high probability of the

[1] Bussière et al. (2009) develop a 21-country GVAR model in four endogenous variables (exports, imports, output, and the effective exchange rate) and which includes the price of oil as a global variable. On the basis of impulse response analysis and forecast error variance decomposition, their results indicate that the prospects of the surplus and deficit economies are intimately interwoven, and that the US real effective exchange rate and output shocks in particular exert strong effects in the global economy.

[2] See Pesaran, Schuermann, and Smith (2009) for further discussion of the out-of-sample forecasting performance of GVAR models.

[3] In GNS, we define 'balancing improvement' as the case in which there is a balance-of-trade deficit but the balance of trade is improving in the sense that export growth exceeds import growth (i.e. the deficit is reducing). By contrast, an 'unbalancing improvement' occurs when there is a trade surplus and the balance of trade is improving (i.e. the surplus is increasing). Our

transition from surplus to deficit in the Eurozone and Japan. Our subsequent experience of the global recession has largely validated these forecasts.

Our final contribution in this chapter is to extend the scenario-based approach beyond probabilistic forecasting and into the context of counterfactual analysis. We show that by working with linear combinations of impulse response functions, one can evaluate the effect of a wide variety of potentially complex shocks or policy interventions at the regional, national, or global levels conditional on the estimated model parameters. To illustrate the principle, we investigate the effect of an oil price shock and a real depreciation of the Renminbi on the balance of trade in each of our focus countries. We then consider two more complex scenarios, which more fully exploit the global nature of the model. Firstly, we evaluate the impact of a concerted interest rate hike in each of our focus countries on their respective trade balances. Secondly, we develop a crude scenario relating to a deepening of the US–China imbalance by considering simultaneous positive US import and Chinese export shocks. The results of these experiments highlight the intimate linkage between the US and China in the global economy.

This chapter proceeds in five sections. Section 7.2 briefly outlines the structure of the GNS GVAR model. Section 7.3 discusses the application of probabilistic forecasting to address a variety of issues relating to the balance of trade, while Section 7.4 focuses on the use of combined impulse responses for counterfactual scenario analysis. Section 7.5 concludes.

7.2 An outline of the GNS model

The GNS GVAR model consists of $N+1$ economies indexed by $i = 0, 1, \ldots, N$. We estimate CVARX*(2,2) models for each economy on a set of country-specific domestic variables denoted by an $m_i \times 1$ vector $\boldsymbol{x}_{it}$ and a corresponding set of weakly exogenous country-specific foreign variables denoted by an $m_i^* \times 1$ vector $\boldsymbol{x}_{it}^* = \sum_{j=0}^{N} w_{ij}\boldsymbol{x}_{jt}$, where $\sum_{j=0}^{N} w_{ij} = 1$, and $w_{ii} = 0$. Following Shin (2009), we also allow for country-specific structural breaks in the CVARX* models in order to yield improved estimation and forecasting results, especially for those East Asian countries severely affected by the 1997 currency crisis and for those South American countries that suffered hyperinflation in the 1980s.[4]

These country-specific models are estimated using quarterly data spanning the period 1980q2–2007q2 for the same set of 33 countries/26 regions

definitions of 'balancing deterioration' and 'unbalancing deterioration' follow in a straightforward manner—see Subsection 7.3.3 for further details.

[4] For a detailed derivation of the model the reader is referred to GNS (including the Statistical Annex) and also to Garratt, Lee, Pesaran, and Shin (2006, GLPS), DdPS, and to Chapter 2 in this book.

Table 7.1. Details of the country-specific models in the GVAR framework.

Order	Country	Code	*r*	*n*	*k*	Probable Cause of Break
0	US	US	3	7	3	
1	Eurozone*	EUR	3	7	5	Introduction of the Euro (1999Q1)
2	Japan	JAP	6	7	5	The real-estate/stock market crash (1992Q1)
3	UK	UK	3	7	5	Departure from the ERM (1992Q4)
4	Norway	NOR	3	7	5	
5	Sweden	SWE	4	7	5	
6	Switzerland	SWI	5	7	5	
7	Canada	CAN	3	7	5	
8	Australia	AUS	3	7	5	
9	New Zealand	NZ	3	7	5	
10	South Africa	SAF	3	7	5	
11	Argentina	ARG	5	7	5	Effects of the Convertibility Plan (1991Q4)
12	Brazil	BRA	3	7	5	Effects of the Real Plan (1994Q4)
13	Chile	CHL	4	7	5	
14	Mexico	MEX	4	7	5	Mexican Peso crisis (1995Q2)
15	India	IND	3	7	5	
16	Korea	KOR	4	7	5	S.E. Asian crisis (1997Q4)
17	Malaysia	MAL	5	7	5	S.E. Asian crisis (1997Q3)
18	Philippines	PHI	3	7	5	S.E. Asian crisis (1997Q4)
19	Singapore	SNG	4	7	5	
20	Thailand	THA	4	7	5	S.E. Asian crisis (1997Q3)
21	China	CHN	3	6	5	
22	Indonesia	INS	4	6	5	S.E. Asian crisis (1997Q3)
23	Peru	PER	4	6	5	Dollarisation; 'Washington consensus' (1994Q3)
24	Turkey	TUR	2	6	5	
25	Saudi Arabia	SAR	4	5	5	

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

employed in the DdPS GVAR model described in Chapter 2 (for further details, see Table 7.1).[5] Our selection of variables for the GNS model is similar to that of Chapter 2, but with the omission of the long-term interest rate and the addition of real exports and real imports, which are included to permit the analysis of global imbalances via the balance of trade. Therefore, we include the short-term nominal interest rate (r_{it}), the log of real imports (im_{it}), the log of real exports (ex_{it}), the log of real equity prices (q_{it}), the rate of inflation (Δp_{it}), the log of real output (y_{it}), and the log of the oil price

[5] Table 7.1 reproduces the relevant sections of Table 1 in GNS. The countries included in the model are as follows: (0) US; (1) Eurozone; (2) Japan; (3) UK; (4) Norway; (5) Sweden; (6) Switzerland; (7) Canada; (8) Australia; (9) New Zealand; (10) South Africa; (11) Argentina; (12) Brazil; (13) Chile; (14) Mexico; (15) India; (16) Korea; (17) Malaysia; (18) Philippines; (19) Singapore; (20) Thailand; (21) China; (22) Indonesia; (23) Peru; (24) Turkey; and (25) Saudi Arabia. Detailed pre-testing conducted in GNS confirms that the majority of variables are $I(1)$, that structural breaks are present in a number of country-specific models, and that the hypothesis of weak exogeneity cannot generally be rejected for the foreign variables.

(p_t^o). The weakly exogenous foreign series are computed as weighted averages of the data for the remaining N countries in the model and are denoted by an asterisk (e.g. y_{it}^* denotes foreign real output). Lastly, we follow DHPS and define the log real effective exchange rate as $re_{it} = ee_{it} + p_{it}^* - p_{it}$. Note that $ee_{it} + p_{it}^* - p_{it} = \left(e_{it} - p_{it}\right) - \left(e_{it}^* - p_{it}^*\right) = \tilde{e}_{it} - \tilde{e}_{it}^*$, where e_{it} is the nominal exchange rate *vis-à-vis* the US dollar, $e_{it}^* = \sum_{j=0}^{N} w_{ij}e_{jt}$, $ee_{it} = \sum_{j=0}^{N} w_{ij}e_{ijt}$ is the nominal effective exchange rate, p_{it} the national price level, and p_{it}^* the foreign price level.

In the majority of cases (i.e. $i = 1, 2, \ldots, 20$), the CVARX* models include the following endogenous $I(1)$ variables: $\boldsymbol{x}_{it} = \left(re_{it}, r_{it}, im_{it}, ex_{it}, q_{it}, \Delta p_{it}, y_{it}\right)'$. Given data constraints for countries $i = 21, 22, \ldots, 24$, we set $\boldsymbol{x}_{it} = (re_{it}, r_{it}, im_{it}, ex_{it}, \Delta p_{it}, y_{it})'$, while for country $i = 25$ we use $\boldsymbol{x}_{it} = (re_{it}, im_{it}, ex_{it}, \Delta p_{it}, y_{it})'$. For all of these country-specific models, the vector of weakly exogenous $I(1)$ foreign variables is defined as $\boldsymbol{x}_{it}^* = \left(p_t^o, r_{it}^*, q_{it}^*, \Delta p_{it}^*, y_{it}^*\right)'$. Lastly, as in DdPS, the US is treated as the reference country and we assume that its exchange rate is determined in the N remaining country-specific models. We therefore set $\boldsymbol{x}_{0t} = \left(p_t^o, r_{0t}, im_{0t}, ex_{0t}, q_{0t}, \Delta p_{0t}, y_{0t}\right)'$ while $\boldsymbol{x}_{0t}^* = \left(\tilde{e}_{0t}^*, \Delta p_{0t}^*, y_{0t}^*\right)$. Note that re_{0t} is excluded and p_t^o included in the set of endogenous variables for the US. Furthermore, we include $\tilde{e}_{0t}^*$ among the weakly exogenous foreign variables, but we exclude both r_{0t}^* and q_{0t}^* as they are unlikely to be weakly exogenous for the US in practice. Finally, note that the omission of ex_{it}^* and im_{it}^* from the set of weakly exogenous variables in all cases reflects the fact that in a model with complete coverage of world trade, the total imports (exports) of country i will be equal to its trade-weighted foreign exports (imports).

As described in Chapter 2, in order to construct the GVAR model, one must simply collect the country-specific domestic variables into a vector of global endogenous variables. In so doing, and in order to maintain the logical consistency of the global system, we replace re_{it} with $\tilde{e}_{it}$ and we also include $\tilde{e}_{0t}$ for the US. Denoting the resulting $(m+1) \times 1$ vector of intermediate global variables as $\tilde{\boldsymbol{x}}_t$, it follows that we may write $\boldsymbol{z}_{it} = \left(\boldsymbol{x}_{it}', \boldsymbol{x}_{it}^{*\prime}\right)' = \boldsymbol{W}_i\tilde{\boldsymbol{x}}_t$, where the $\boldsymbol{W}_i$ are $\left(m_i + m_i^*\right) \times (m+1)$ link matrices and $m = \sum_{i=0}^{N} m_i$. In GNS, we adopt the convention of DdPS and define the link matrices using bilateral trade averages over 1999–2001, although we note that the choice of weighting scheme is of secondary importance. It is then a straightforward matter to rewrite the CVARX*(2, 2) models in terms of $\tilde{\boldsymbol{x}}_t$ and stack the country-specific models to yield the GVAR model as follows:

$$\boldsymbol{H}_0\tilde{\boldsymbol{x}}_t = \boldsymbol{h}_0^* + \boldsymbol{h}_1 t + \boldsymbol{H}_1\tilde{\boldsymbol{x}}_{t-1} + \boldsymbol{H}_2\tilde{\boldsymbol{x}}_{t-2} + \boldsymbol{u}_t, \tag{7.1}$$

where $\boldsymbol{h}_0^*$ collects the intercept and terms relating to the break dummies (see GNS), $\boldsymbol{h}_0^* = \left(\boldsymbol{h}_{00}^{*\prime}, \boldsymbol{h}_{10}^{*\prime}, \ldots, \boldsymbol{h}_{N0}^{*\prime}\right)'$, $\boldsymbol{h}_1 = \left(\boldsymbol{h}_{01}', \boldsymbol{h}_{11}', \ldots, \boldsymbol{h}_{N1}',\right)'$, $\boldsymbol{u}_t =$

$(\boldsymbol{u}'_{0t}, \boldsymbol{u}'_{1t}, \ldots, \boldsymbol{u}'_{Nt})'$ and $\boldsymbol{H}_i = (\boldsymbol{W}'_0\boldsymbol{A}'_{0i}, \boldsymbol{W}'_1\boldsymbol{A}'_{1i}, \ldots, \boldsymbol{W}'_N\boldsymbol{A}'_{Ni})'$ for $i = 0, 1, 2$. Given that $\tilde{e}_{0t}$ is not included in the set of US variables used to estimate the CVARX* model but it is included in $\tilde{\boldsymbol{x}}_t$, we must impose one additional restriction; in this case it follows that $e_{0t} = 0$ and therefore that $\tilde{e}_{0t} = -p_{0t}$. Imposing this restriction in $\tilde{\boldsymbol{x}}_t$ results in the final vector of global endogenous variables used in the GVAR model, $\boldsymbol{x}_t$. By use of two $(m+1) \times m$ selection matrices, $\boldsymbol{S}_0$ and $\boldsymbol{S}_1$ (defined in detail in the Statistical Annex to GNS) we may now write the structural GVAR model as follows:

$$\boldsymbol{F}_0\boldsymbol{x}_t = \boldsymbol{h}_0^* + \boldsymbol{h}_1 t + \boldsymbol{F}_1\boldsymbol{x}_{t-1} + \boldsymbol{F}_2\boldsymbol{x}_{t-2} + \boldsymbol{F}_3\boldsymbol{x}_{t-3} + \boldsymbol{u}_t, \tag{7.2}$$

where $\boldsymbol{F}_0 = \boldsymbol{H}_0\boldsymbol{S}_0$, $\boldsymbol{F}_1 = \boldsymbol{H}_1\boldsymbol{S}_0 + \boldsymbol{H}_0\boldsymbol{S}_1$, $\boldsymbol{F}_2 = \boldsymbol{H}_2\boldsymbol{S}_0 - \boldsymbol{H}_1\boldsymbol{S}_1$, and $\boldsymbol{F}_3 = -\boldsymbol{H}_2\boldsymbol{S}_1$. We assume that the error process is serially uncorrelated but may exhibit cross-country contemporaneous correlation. The reduced-form GVAR is obtained in the usual manner by pre-multiplying throughout by $\boldsymbol{F}_0^{-1}$. The reader should note that in the special case of the US, we are therefore solving for the price level, as opposed to inflation (see also DHPS).

7.3 Probabilistic forecasting

There is an increasing recognition of the importance of conveying relevant information about the precision of forecasts to their end-users (Giordani and Söderlind, 2003). Such information is crucial in achieving a balanced public evaluation both of the forecasts and of the policies that they inform (Casillas-Olvera and Bessler, 2006). However, GLPS observe that traditional forecasts provide little information about the degree of forecast uncertainty. Indeed, forecast intervals only convey such information indirectly through the choice of their width. The fan chart forecasts provided by an increasing number of central banks represent a significant improvement but they still suffer from two main shortcomings. Firstly, given the subjectivity in their construction, their accurate replication by independent researchers is generally not possible. Secondly, they are poorly suited to those wishing to evaluate joint event probabilities.

Given these shortcomings, GLPS propose probabilistic forecasting as a superior means of conveying relevant information about the density or the distribution of forecast outcomes. Probabilistic forecasts are constructed by computing the conditional probability that a given event or scenario will occur over a defined horizon via stochastic simulation.[6] The variety of

[6] The simulation procedure that we follow in GNS is based on a parametric stochastic bootstrap using 1000 replications. We allow for future uncertainty under the assumption that the model parameters are known and are not subject to variation. The extension to the case of parameter uncertainty is straightforward. Full computational details in the context of the GVAR model can be found in Section 3 of the Statistical Annex to GNS.

scenarios that can be evaluated in this way is limited only by the variable set used to estimate the model. The potential of GVAR models to analyse high-dimensional data sets with extensive geographic coverage therefore renders them particularly well-suited to scenario-based analyses, especially where one's interest is supranational.

7.3.1 *Predictive distribution functions*

In its simplest form, the probabilistic h-step-ahead forecast for a given variable may be represented by the corresponding predictive distribution function (PDF). The h-period-ahead PDF for the variable x_t reports the conditional probability that $x_{t+h} \leq a$, where a is a threshold value of interest. Figure 7.1 reports the PDFs for the change in the trade balance (defined as $\Delta tb_{i,t+h} = \Delta\left(ex_{i,t+h} - im_{i,t+h}\right)$ and expressed in percentage points per annum) for the US, the Eurozone, Japan, and China. We report results for threshold values of $\Delta tb_{i,t+h}$ ranging between -10% and 30% per annum at the 1, 4, 8 and 12 quarter ahead horizons. Recall that the data set ends at 2007q2 so the one-quarter ahead forecasting horizon relates to 2007q3, the four-quarter ahead horizon to 2008q2, and so forth. Following GNS, we will focus on these four countries throughout our analysis.

First, consider the one-quarter-ahead PDF for the US in panel (a). The steepest section of the curve indicates the range of values of Δtb_{t+1} which

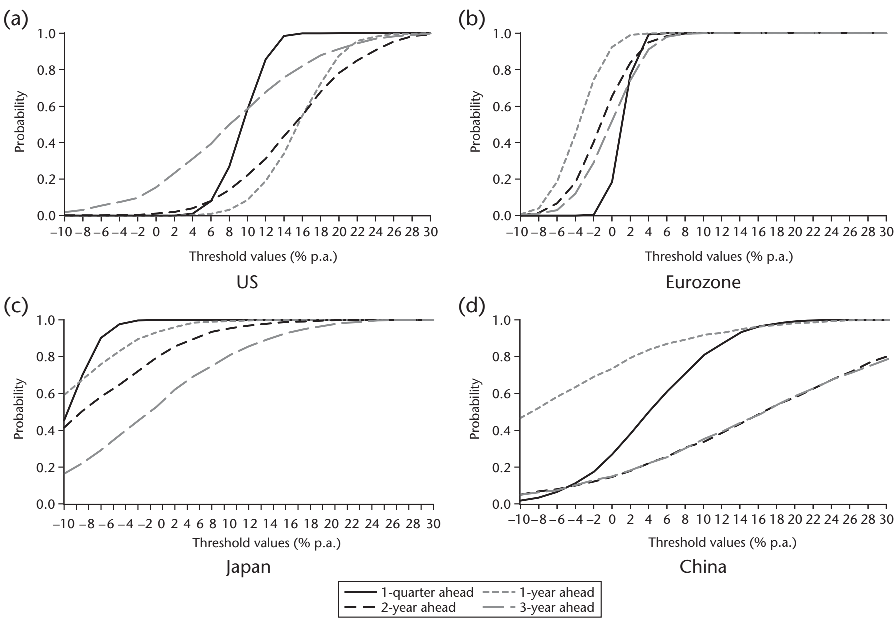

Figure 7.1. PDFs for changes in the balance of trade.

are most probable; here, a range of roughly +6 to +14 percentage points. Therefore, in 2007q3, the model predicts a non-negligible improvement in the US balance of trade. Moving on to the one- and two-year-ahead PDFs, the steep section has shifted rightwards in each case, indicating a high probability of a more marked improvement in the trade balance at these longer horizons. Note also that the PDFs flatten gradually as the forecast horizon rises, indicating greater forecasting uncertainty at longer horizons. Finally, at the three-year-ahead horizon, the model predicts a smaller improvement in the trade balance, although at this horizon the forecast is subject to considerable uncertainty.

Panels (b) and (c) relate to the Eurozone and Japan, respectively. In both cases, the model indicates a high probability of deterioration in the balance of trade at all horizons, although the degree of uncertainty in the Japanese case rises rapidly with the forecasting horizon. (Note, however, that negative growth in the trade balance need not imply a trade deficit.) Finally, panel (d) shows the case of China. Here, the one-year-ahead PDF stands out from the others, all of which indicate a high probability of an improvement in the balance of trade. By contrast, the one-year-ahead PDF shows a high probability of a deterioration. This pattern will recur more clearly in the probabilistic event forecasts discussed below.

7.3.2 *Probabilistic forecasts for single events*

A more easily interpreted representation of the probabilistic forecasts is achieved by computing the estimated probability that a given event will occur over the forecasting horizon, $h = 1, 2, \ldots$. This technique has an intuitive appeal, enabling the forecaster to directly define an event or scenario of interest. In GNS, we consider events relating to the inflation target, the rate of economic growth, and the balance of trade. We will limit our attention here to the latter to conserve space. Maintaining the same notation as GNS, we consider the following events over the horizon $h = 1, \ldots, 12$:

- E Balance of trade deficit, defined as $ex - im < 0$; and
- F Balance of trade improvement, defined as $\Delta ex - \Delta im > 0$.

Figure 7.2 reproduces Figures 3(a) and (b) from GNS. Figure 7.2(a) shows the probability of a balance of trade surplus in each country over a 12-quarter horizon (i.e. the complement of event E, denoted $\overline{E}$). The results indicate that the US will remain a persistent deficit country, China will maintain its persistent surplus, and the EU and Japan will occupy an intermediate position. Specifically, the probability of China maintaining a surplus over the forecast horizon is essentially 100%. Similarly, the probability of the US deficit being maintained is close to 100% at all horizons. By contrast, the

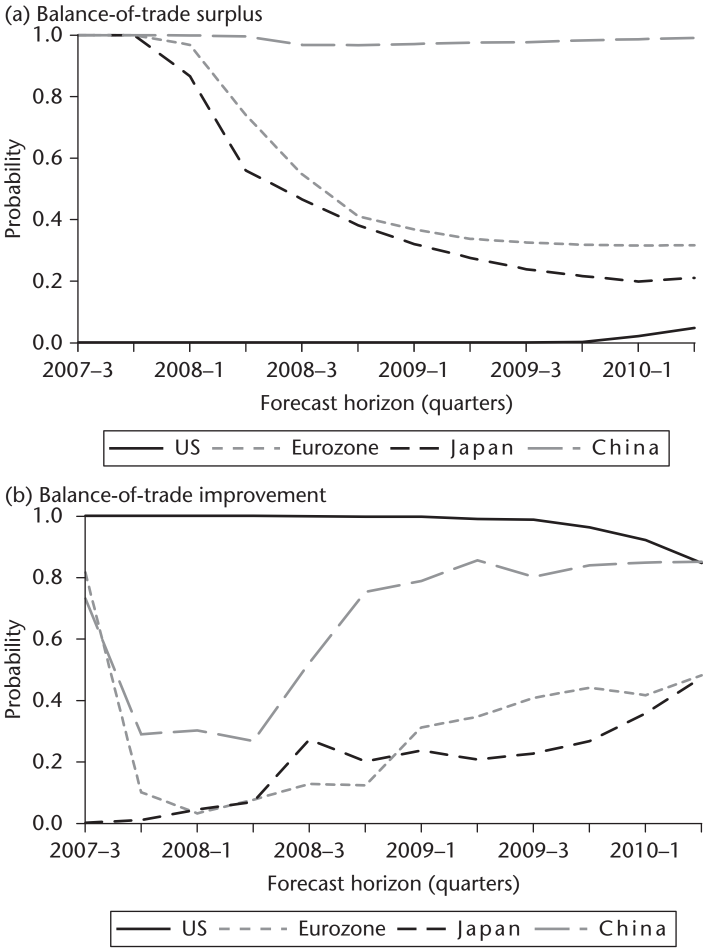

Figure 7.2. Single-event probability forecasts for the balance of trade.

forecasts indicate a non-negligible probability of the Eurozone and Japan moving from surplus into deficit, with the probability of a surplus in each country falling to approximately 30% after two years. Panel (b) reports the estimated probability of a balance of trade improvement in each country (event *F*), shedding some more light on these patterns. Our simulations indicate a very high probability of an improvement in the balance of trade in the US, and also in China after an initial dip, which reflects the period of deterioration identified by the one-year-ahead PDF in Figure 7.1(d). By contrast, however, the probability of improvement in the Eurozone and Japan becomes zero after two quarters and remains relatively low for a number of quarters thereafter. The similarity to the PDFs described above is easily seen, although it is clear that the probabilistic forecasts are more easily interpreted.

7.3.3 *Probabilistic forecasts for joint events*

While the event forecasts reported in Figure 7.2 are considerably more user-friendly than the PDFs in Figure 7.1, it remains non-trivial to evaluate the probability of joint outcomes. However, it is a straightforward matter to define joint events and then to evaluate the conditional probability that they will occur over a given horizon. In this specific case, we are interested in seeing whether external trade movements are likely to bring about a rebalancing of the accounts (balancing) or a further departure from a balanced budget (unbalancing). To do so, we consider each of the four possible combinations of events E and F and construct a simple classificatory system based on the resulting joint events as follows:

- $E \cap F$ balance of trade deficit and improvement—*balancing improvement*;
- $E \cap \overline{F}$ balance of trade deficit and deterioration—*unbalancing deterioration*;
- $\overline{E} \cap F$ balance of trade surplus and improvement—*unbalancing improvement*; and
- $\overline{E} \cap \overline{F}$ balance of trade surplus and deterioration—*balancing deterioration*.

Figure 7.3 reports the probabilities of each of these joint events, and reproduces Figures 3(c)–(f) in GNS. We observe a very high probability of balancing improvement in the US, and a similarly high probability of unbalancing improvement in China, at least after mid-2008. These forecasts have been largely validated by subsequent experience; the US did experience a considerable improvement between 2008 and 2009, while over the same period the Chinese trade surplus grew considerably. Meanwhile, for the Eurozone and Japan, the probability of balancing deterioration is initially high but rapidly switches into a growing probability of unbalancing deterioration, which does not start to fall appreciably until 2009 for the Eurozone and 2010 for Japan. This pattern indicates a high probability of initial reductions in the European and Japanese trade surpluses (as of 2007q2) translating into trade deficits by 2008. Indeed, subsequently we have seen many countries within the Eurozone (and indeed the EU-17 bloc as a whole) run considerable deficits in 2008 and 2009, while Japan recorded a non-negligible trade deficit in late 2008 and early 2009.[7]

[7] The impressive out-of-sample forecasting performance of the GNS model is substantiated by a raft of statistical tests reported in the original paper. In particular, the model achieves a hit rate of 74% in relation to the four focus countries, while formal evaluation using the Kuipers

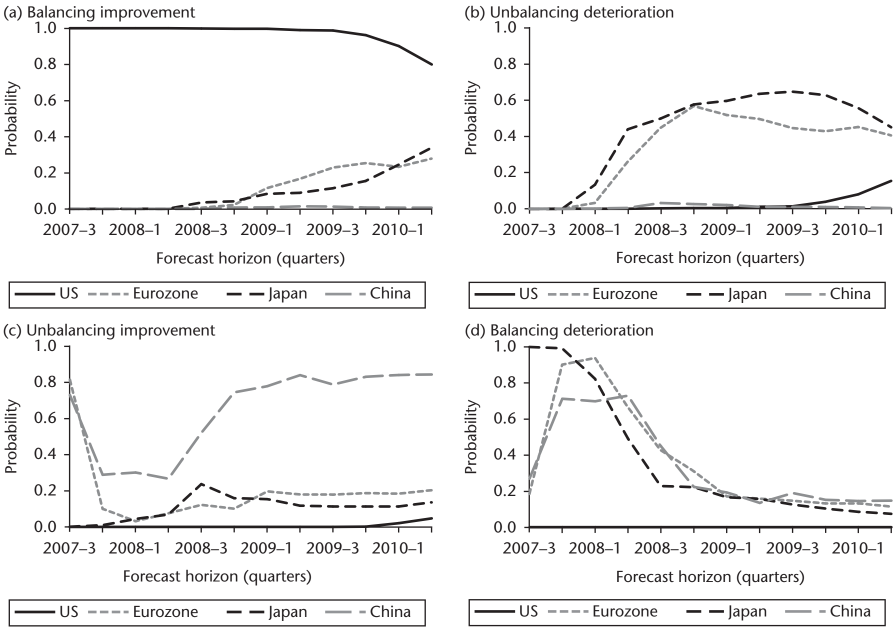

Figure 7.3. Joint-event probability forecasts for the balance of trade.

The joint event forecasts presented in Figure 7.3 offer a clear and easily communicable synthesis of the information contained in Figures 7.1 and 7.2. Indeed, the probabilistic four-way typology developed above provides an intuitive means of conveying expectations and forecasts relating to the issue of global imbalances to a wide and non-specialist audience. Moreover, the flexibility of scenario-based forecasting is such that the range of applications to which it can be usefully applied is almost limitless. Perhaps the most appealing development of the technique would be the provision of a user-friendly platform, which would allow the end-user to define scenarios of interest directly. This would represent a significant improvement on the fan chart forecasts currently favoured by many central banks.

7.4 Counterfactual scenario analysis

Our focus to this point has been on out-of-sample probabilistic forecasting of single and joint events or scenarios. We now consider the use of

score and the Pesaran–Timmermann (1992) statistic strongly supports the directional accuracy of its forecasts. Furthermore, the GNS model outperforms the benchmark AR and random walk forecasts at longer horizons, a finding which we attribute to the inclusion of global linkages in the GVAR model that are absent from the benchmark models.

counterfactual impulse response analysis, which is well established in the context of GVAR models. Typically, the focus is on evaluating the effect of a hypothetical impulse in the error process of a single equation in the VAR system on one or more of the variables in the system individually. In a linear model, however, one can evaluate more complex scenarios by considering appropriate combinations of impulse response functions. Therefore, in keeping with our interest in joint event forecasting, we will demonstrate how one can conduct potentially complex counterfactual exercises by exploiting linear combinations of impulse response functions. We will first consider the case of combined responses to a simple shock (e.g. the response of the trade balance defined as a linear combination of exports and imports to an oil price shock), before moving on to the case of combinations of shocks.

7.4.1 *Linear combinations of responses to individual shocks*

The effect of a given shock on the trade balance can be evaluated as a linear combination of the responses of exports and imports to the shock. For example, assuming a shock to the oil price, p^o, the response of the trade balance is simply $R_{t+h}^{tb,p^o} = R_{t+h}^{ex,p^o} - R_{t+h}^{im,p^o}$, where R_{t+h}^{x,p^o} denotes the response of the variable x to the oil price shock after h periods. A similar approach is pursued by Greenwood-Nimmo and Shin (2012) in their analysis of the real interest rate response to inflation and output gap shocks in a VECM model of the Fed's monetary policy reaction function.

Figure 7.4(a) depicts the effect of a one standard deviation positive oil price shock on the balance of trade in each of our four focus countries. This represents a quarterly increase of approximately 13% in the price of oil. The shock results in a profound deterioration of the balance of trade in the US, Japan, and China, with the impulse responses settling at between −8 and −10% p.a. in the long run. By contrast, the effect is negative but relatively muted in the Eurozone. Economic activity in the US and China is relatively energy intensive, with each economy generating just 5.6 and 3.5 constant 2005 PPP US$ per kilogram of oil equivalent in 2007, respectively. The Japanese economy, by contrast, is less energy-intensive (7.9$05p/koe), but it is also much more heavily reliant on imported oil. Whereas energy imports in 2007 accounted for 29% and 7% of energy usage in the US and China, respectively, the equivalent figure for Japan is 82%. The Eurozone, meanwhile, has the lowest energy intensity of activity of our focus economies at 8.3$05p/koe. Moreover, the Eurozone is considerably less reliant on imported oil than Japan, with imports amounting to 63% of usage in our eight Eurozone countries.[8] Taken together, these features of the

[8] Energy intensity data comes from the World Bank (series EG.GDP.PUSE.KO.PP.KD). Data for energy imports also comes from the World Bank (series EG.IMP.CONS.ZS). Eurozone figures are calculated as PPP-GDP-weighted averages of the figures for each of our eight Eurozone economies.

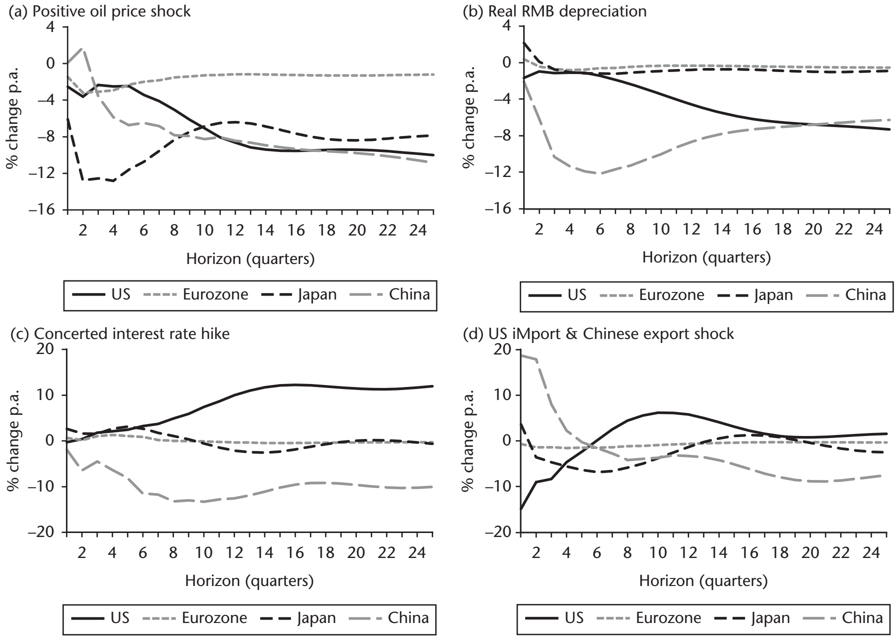

Figure 7.4. Generalized impulse response functions w.r.t. named shocks.

European economy offer a potential explanation of the relative insensitivity of its trade balance to the oil shock. The presence of strong internal markets and major oil producers including Denmark, Norway, and the UK within the European Economic Area are also likely to be important explanatory factors.

Figure 7.4(b) relates to a one standard deviation shock to the Chinese real effective exchange rate, which equates to a real quarterly depreciation of the Renminbi of 4.29%. In both the Eurozone and Japan, we observe only a moderate response of the balance of trade. By contrast, the US experiences a profound deterioration of its trade balance arising through a reduction in export activity set against largely unaffected import levels. This suggests that while a weakening of the Renminbi may not lead to significant increases in US import activity, it may exert considerable pressure on US exporters as their products become relatively more expensive both within China and on global markets where they compete with Chinese goods.

Interestingly, despite strong real export growth in China after the shock, the overall effect on the balance of trade is negative owing to pronounced import growth. Cheung et al. (2009) also document a positive response of Chinese imports to a Renminbi depreciation. A strong linkage between export and import activity in China is not unexpected as the domestic content of Chinese exports is generally quite low and the importation of intermediate inputs is prevalent (Koopman et al., 2008). Indeed, during the last years of our sample, the Chinese government actively sought to promote the importation of intermediate inputs within its export-oriented free-trade zones by waiving the usual customs duties in such cases (UNCTAD, 2000, pp. 76–7).

In the early years of the global financial crisis, many commentators argued that an appreciation of the Renminbi would reduce the imbalance between the US and China by reducing both China's capital account deficit and its trade surplus (e.g. Krugman, 2010). By the symmetry of our linear framework, an equivalent appreciation of the Renminbi would result in the same effects depicted in Figure 7.4(b) but with opposite signs. Therefore, our results only partially support this view. In our framework, a Chinese appreciation would be associated with an improvement in the US trade balance, but it would also be associated with an improvement in the Chinese trade balance. Similarly, the results adduced by Cheung et al. suggest that the effects of plausible changes in the exchange rate are too small to exert a decisive influence on the US–Chinese imbalance. The overall effect of a Renminbi revaluation is, therefore, ambiguous. Indeed, in recent years the Renminbi has appreciated strongly against the dollar but significant imbalances remain.

7.4.2 *Responses to linear combinations of shocks*

Given its global nature, the evaluation of supranational shocks and/or policy interventions represents a natural application of the GVAR framework. Unlike regional or national VAR models, GVAR models can be used to assess the effect of concerted shocks and/or policy actions taking place in a variety of sovereign states by studying appropriate combinations of impulse response functions.

Figure 7.4(c) shows the expected response of the balance of trade to a concerted simultaneous monetary tightening of 50 basis points in each of our focus countries. Such a tightening may be observed in response to rising global inflationary pressures, for example. It is interesting to note that the overall effect on the balance of trade in the Eurozone and Japan is negligible but that the effects in the US and China are of roughly equal size, but act in opposite directions. The Chinese balance of trade deteriorates markedly at approximately 10% p.a. following the shock. Careful scrutiny of the underlying impulse responses reveals that the combined shock is followed by further increases in the Chinese interest rate, while the opposite pattern is generally observed in our other focus countries, especially Japan, where the interest rate rapidly declines following the initial shock. The combination of these effects offers some insight into the deterioration in the Chinese trade balance. An interesting possibility is that the development of an interest rate differential between China and the US may reduce China's appetite for US debt, thereby reducing its capital account deficit and helping to rebalance its current account and trade surpluses. Furthermore, the interest rate differentials lead to a pronounced appreciation of the Renminbi which, as discussed above, is likely to be an important factor driving the improvement in the US trade position. The strength of the association between the US and Chinese trade balances is a striking illustration of the interlinkages between their economies.

To further investigate these linkages, Figure 7.4(d) considers the case of simultaneous 5% increases in both US real imports and Chinese real exports relative to their 2007q2 levels. This combination of shocks can be viewed as a crude representation of a deepening of the US–China imbalance. In this case, while the Eurozone and Japan both experience export and import growth, it is balanced such that the overall effect on the balance of trade is negligible. By contrast, and as expected, we observe a substantial short-run deterioration of the US trade balance coupled with a considerable improvement in the Chinese case. However, in the medium term, these effects diminish to insignificance and then reverse to a modest extent in the long run. This effect arises because the US import shock has relatively low persistence and dies away within three years. Similarly, the Chinese export shock converges to a level of approximately 40% of its value on impact, while the increased Chinese import activity generated by the shock shows much greater persistence. This linkage between Chinese exports and imports is the result of its growth strategy discussed above.

The most striking insight from these counterfactual scenarios is the dominant impact of the US and China in the world economy. Although the Eurozone and Japan are very large economies, it is the imbalances and the co-dependence that have evolved between the US and China that critically underpin our results. To reiterate one of our opening remarks in this chapter, efforts to analyse the causes and forecast the development of these imbalances are clearly of paramount importance.

7.5 Concluding remarks

Using the GVAR model developed in GNS as the basis of our analysis, we have shown that event-based probabilistic forecasting is a useful tool for improving the transparency of macroeconomic forecasts and increasing their accessibility to non-specialists. Similarly, we have shown that the effects of global shocks and concerted supranational policy interventions can be analysed using GVAR models in a straightforward manner by constructing linear combinations of impulse response functions.

GVAR models are particularly well-suited to such scenario-based applications as they provide a vehicle for the analysis of singularly rich global data sets. The usefulness of scenario-based modelling is limited mainly by the range of interesting and realistic scenarios that one can feasibly construct. In turn, the number of scenarios that can be analysed using a given model is an increasing function of the number of variables in that model. It therefore follows that GVAR models provide much greater scope for scenario-based analyses than traditional national or regional VAR models. Moreover, by explicitly modelling regional and global linkages in an intuitive data-driven manner, GVAR models provide a much more comprehensive framework for the analysis of global scenarios than was previously available.

The over-arching implication of our results is that the global imbalances centred around the US and China are deeply rooted and complex phenomena. In particular, the roughly equal but oppositely signed response of the US and Chinese trade balances in response to a concerted monetary tightening reveals the extent of the dependence structure that has developed between their respective economies. The importance of developing global models capable of capturing the fundamental linkages and tensions introduced by such imbalances is therefore plain to see. GVAR models provide a promising means by which to improve our understanding not just of global imbalances themselves, but also of the effect of national, regional, and global shocks in an unbalanced world economy.

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8

Short- and medium-term forecasting using 'pooling' techniques

L. Vanessa Smith

8.1 Introduction

This chapter considers the problem of forecasting economic and financial variables across a large number of countries in the global economy.[1] There are several questions one needs to consider when dealing with such problems.

1. What variables are to be included in the model? Should they be treated separately (two isolated equations) or together, say in a VAR?
2. Should foreign variables be considered? If so, should they be endogenized as well?
3. How important are co-integrating relationships, either across variables within a country or across countries (PPP relationships come to mind)?
4. How should one address the ever-present problem of structural breaks, which may occur multiple times in any one or several of the relationships in the forecasting model under consideration?

The global vector autoregressive (GVAR) model is employed for dealing with some of these issues. Nonetheless, with a modelling task of this size, it would be surprising if a single model were universally preferred over any other. Recognizing that a broader set of models might be needed to tackle the problem, a natural step is to turn to the model-averaging literature for a solution—Bayesian model averaging is a prominent example; see Timmermann (2006) for a recent survey. The standard Bayesian model-averaging

[1] This chapter is based on Pesaran, Schuermann, and Smith (2009).

approach implicitly assumes that the underlying data-generating process and the models remain stable. Thus, simply averaging across models does not address the structural break problem. To do so, forecasts can be combined based on the same model but estimated over different estimation windows, as suggested by Pesaran and Timmermann (2007). In this way, parameter estimates are automatically allowed to vary over time. This strategy is especially useful when not only the nature but also the number of breaks is unknown.

The approach in this chapter relies on combining the two averaging approaches—across models and across estimation windows—to arrive at an average-average (AveAve) forecast. The basic GVAR model presented in Chapter 2, previously estimated over the 1979q1–2003q4 period by DdPS, is used here to generate out-of-sample one-quarter- and four-quarters-ahead quarterly forecasts of real output, inflation, and interest rates, real equity prices, and exchange rates across 26 countries/regions over the subsequent eight quarters: 2004q1–2005q4. Given the size of the modelling problem—134 variables from 26 regions made up of 33 countries covering about 90% of world output—and the heterogeneity of economies considered—industrialized, emerging, and less developed countries—as well as the very real likelihood of possibly multiple structural breaks, averaging across both models and windows makes a significant difference.

The aim is to shed light on three main issues of particular interest: first to evaluate the performance of forecast averaging strategies in the GVAR context; second, to see if the AveAve forecasts from the GVAR can beat the forecasts from typical benchmark models such as univariate autoregressive and random walk models; finally, to assess the extent to which using financial variables such as long-term interest rates and real equity prices are likely to be helpful in forecasting real output and inflation in the world economy.

The plan of the chapter is as follows. Section 8.2 considers the range of issues involved in the course of building a global forecasting model, including model averaging and forecast pooling. Section 8.3 discusses alternative specifications of the GVAR used in the forecasting exercise, as well as different estimation windows. Section 8.4 introduces the benchmark models against which the GVAR will be compared and discusses methodological considerations in forecast evaluation. Section 8.5 presents some results, and section 8.6 provides some concluding remarks.

8.2 Model building, evaluation, and testing: issues and trade-offs

In the course of developing a model one typically goes through three stages: building, which is done entirely on an in-sample basis; evaluation, which may involve some form of cross-validation; and real-time use in forecasting and policy analysis. Broadly, the objective in the initial 'build' stage is to focus on statistical significance and goodness-of-fit: which functional form to use, which variables to include, possible relationships among the conditioning variables (captured, for instance, through co-integration), and so on. During evaluation one may test for the presence of structural breaks that might have occurred during the sample used for the 'build' stage. Ideally evaluation is done with a separate sample, though that can often be prohibitively costly. Essentially, these first two stages can be considered as trading off bias (build) and efficiency (evaluate). Finally, the model is put to the test: genuine out-of-sample forecast evaluation. At each stage the researcher is faced with a plethora of choices, some of which will be considered in this chapter.

The GVAR framework allows for a rich structure which, if correct—and relatively stable—should yield better forecasts over short and long horizon than simpler competitors. The structure may include trends with co-trending restrictions, across country co-integration, weak cross-country dependence of shocks (innovations), trade relations, and so on. Structural change could occur in any and all of these relations.

8.2.1 *Building a global model*

Some of the issues when constructing a GVAR model include the following. The first and perhaps most obvious decision is which set of variables to choose to adequately capture the real and financial dynamics of the global economy. The first version of the GVAR (PSW) included real output, real money supply, a price index, exchange rates, a short-term interest rate, a stock market index, and the price of crude oil, common to all countries. In the second version of the GVAR (DdPS) the money supply variable was dropped due to lack of a consistent measure across all countries, and a long-term interest rate was added to allow for simple yield curve relationships.

Several other choices need to be made; here are a few, with the final choice in the DdPS model used here, given in parentheses. How to measure foreign variables (use trade shares); which countries to aggregate into regions (depends on the application: for instance, shared geography, e.g. Latin America, or shared currency, e.g. Eurozone); how to aggregate countries into regions (use PPP output weights); how many lags to include, domestic and foreign, by country/region (depends, but largely one, possibly two lags have been typical). More structure through over-identifying long-run restrictions can also be added (Dées, Holly, Pesaran, and Smith, 2007; DHPS).

8.2.2 *Structural breaks and forecast combinations*

There is now considerable evidence that autoregressive models used in economic and financial forecasting are often unstable and subject to structural breaks, despite their success relative to other alternatives. Structural instability is identified by Clements and Hendry (1998, 2006) as a key factor in poor forecast performance. It is also important to note that even if conditional models (e.g. country-specific models in the GVAR) are structurally stable (as it is found to be the case for many of the country models in DdPS), the unconditional model, which is used to generate forecasts, could be subject to structural breaks.

Structural breaks can arise from institutional changes, large macroeconomic shocks, changes in economic policy, just to name a few. Structural breaks can occur in a number of places in the model, from changes in the coefficients to trend breaks to changes in the error variance. Moreover, these changes could occur in one or more relations or in one or more countries, not to mention the possibility of multiple breaks. Even when the point of the break is known, depending on the size of the break there is a trade-off between bias and efficiency—forecasts that use only post-break data are unbiased but could be inefficient as compared to biased forecasts that also include part of the available pre-break observations. The choice of the optimal observation window depends on the full knowledge of the break point as well as the size of the break. These issues are considered in some detail in Pesaran and Timmermann (2007), who also consider a number of alternative procedures that can be used to exploit information on the break points and the sizes of breaks in forecasting.

In general, however, information about breaks is limited, and it is not clear if the optimal window size can be estimated in practice. In view of these difficulties rolling windows of a fixed size are often used in practice, but this comes with its own problems: if one is close to the break date, the optimal window size would be short, but if one is far from the break date, the optimal window would be long. It is also not clear whether the same rolling window size would be appropriate over the full sample period. Whether one uses an expanding or a rolling window in estimation, the resultant forecasts will be based on a single estimation window, which may not be appropriate given that the choice of the estimation window (whether expanding or rolling) has been made in an ad hoc manner.

One possibility would be to extend the idea of pooling of forecasts obtained from different models (but based on the same given estimation window) to pooling of forecasts based on the same model but computed across alternative estimation windows. The rationale behind this approach is very similar—when unsure about the optimal window size, use many different window sizes and then pool the results. This approach has been recently shown by Pesaran and Pick (2011) to possess some optimality properties in the case of forecasting with random walk models subject to one or more breaks.

8.2.3 *Bayesian model averaging in the presence of model instability*

Model averaging and forecast combination have a rich history in statistics and forecasting. An early survey of the literature on forecast combination is provided by Bates and Granger (1969), with Timmermann (2006) providing a more recent survey. Here too there is a wide range of choices faced by the econometrician: what is the set of admissible models, what weighting scheme should be used to combine the forecasts from each model, and so on.

To fix ideas, suppose that up to T observations of the variable of interest are available, $\mathbf{Z}_{T,T} = (\mathbf{z}_1, \ldots, \mathbf{z}_T)$, but that the estimation window is only of length w, $\mathbf{Z}_{w,T} = (\mathbf{z}_{T-w+1}, \ldots, \mathbf{z}_T)$. The future variables to be forecast are denoted $\mathbf{Z}_{T+1,h} = (\mathbf{z}_{T+1}, \ldots, \mathbf{z}_{T+h})$. The forecasting problem can be described as estimating the forecast probability density function, namely $\Pr(\mathbf{Z}_{T+1,h}|\mathbf{Z}_{w,T})$. To do so, a model $\mathfrak{M}_m$ is needed, which in turn needs to be estimated over the estimation window of size w from the end of the estimation sample at T, to obtain an estimate, $\widehat{\Pr}(\mathbf{Z}_{T+1,h}|\mathbf{Z}_{w,T}, \mathfrak{M}_m)$. In the face of model uncertainty one may want to pool over a total of, say, M models. Using Bayes' rule yields the familiar Bayesian model averaging expression:

$$\widehat{\Pr}(\mathbf{Z}_{T+1,h}|\mathbf{Z}_{w,T}) = \sum_{m=1}^{M} \widehat{\Pr}\left(\mathfrak{M}_m|\mathbf{Z}_{w,T}\right) \widehat{\Pr}(\mathbf{Z}_{T+1,h}|\mathbf{Z}_{w,T}, \mathfrak{M}_m), \tag{8.1}$$

where $\widehat{\Pr}(\mathbf{Z}_{T+1,h}|\mathbf{Z}_{w,T}, \mathfrak{M}_m)$ is the predictive density of $\mathbf{Z}_{T+1,h}$ conditional on model $\mathfrak{M}_m$, and $\widehat{\Pr}\left(\mathfrak{M}_m|\mathbf{Z}_{w,T}\right)$ is the posterior probability of model $\mathfrak{M}_m$, both estimated over the observation window w.

If a particular model $\mathfrak{M}_m$ is stable over time, then obviously it would be desirable to use the longest sample window possible for estimation, namely $\mathbf{Z}_{T,T}$ in the above notation. The Bayesian model averaging expression given by (8.1), implicitly makes the assumption of model stability, as the underlying parameters are considered to be constant over time. In reality, however, some or all of the models under consideration could be subject to structural breaks and different choices of estimation samples might be warranted. With this in mind, a more pragmatic approach would be to also average each model over different sampling windows, starting from a minimum window size to the largest permitted by the available data set. Allowing for both model and estimation window uncertainty yields

$$\widehat{\Pr}(\mathbf{Z}_{T+1,h}|\mathbf{Z}_{T,T}) = \sum_{m=1}^{M} \sum_{w=T}^{T-W+1} \widehat{\Pr}\left(\mathfrak{M}_m|\mathbf{Z}_{w,T}\right) \widehat{\Pr}(\mathbf{Z}_{T+1,h}|\mathbf{Z}_{w,T}, \mathfrak{M}_m), \tag{8.2}$$

where $\widehat{\Pr}\left(\mathfrak{M}_m|\mathbf{Z}_{w,T}\right)$ may be thought of as the weight attached to model $\mathfrak{M}_m$, $m = 1, \ldots, M$, estimated over the sample window $w = T, T-1, \ldots, T-W+1$, with W the size of the estimation window. The windows are arranged from the longest window of size T to the shortest window of size $T-W+1$.

Bayesian model averaging requires the specification of the prior probability of model $\mathfrak{M}_m$ and a prior probability of the model's coefficients, collected in θ_m, conditional on $\mathfrak{M}_m$, for $m = 1, \ldots, M$. When there is little certainty about which model is the right one, and if in addition the models are subject to structural breaks, the simplicity of equal weights is quite appealing. To be sure, this choice entails risks, as one may consider some bad models that should perhaps have been better left out. It is worth noting, however, that in his handbook survey, Timmermann (2006) reports that across many different empirical applications, the equal weighting scheme tends to beat other forecast combination procedures.

8.3 GVAR models and estimation windows

Modelling a complex system such as the global economy is naturally subject to considerable uncertainties. There are many choices to be made at the level of individual country models—the variables to be included in the country-specific models, the lag orders, the number of co-integrating relations, and whether to impose long- and short-run theory restrictions on the parameters, just to mention a few of the choices. The number of possible GVAR models, even when limiting the focus to uncertainty regarding the number of co-integrating relations and fixing the lag orders p_i and q_i in the individual country VARX*(p_i, q_i) models (or fixing the number of co-integrating relations for each country to its estimated value allowing only for uncertainty with respect to p_i and q_i), is very large and clearly infeasible to deal with in practice. In what follows focus will be only on a limited number of GVAR type models in order to make the analysis feasible and to illustrate the proposed approach.

While it is certainly desirable to consider a large number of models, one needs to be cautious about the models selected so as not to include too many that are a priori obvious not to perform well. The literature on forecasting is typically silent on this issue. Economic theory, if available, could provide some guidance as to a reasonable choice of models. In any case, this is an issue that deserves considerable attention.

In constructing the model space the starting point is the basic GVAR model presented in Chapter 2, though estimated based on data ending in the last quarter of 2003, as in the original DdPS (2007). This seems sensible, since the DdPS-GVAR specification was developed prior to the forecast evaluation period, 2004q1–2005q4. Other GVAR variants can now be developed from the DdPS-GVAR specification. Given the uncertainty regarding the true number of co-integrating relations, one possibility would be to set the number of co-integrating relations for all country-specific models to zero, and thus consider a GVAR model in first differences, to be denoted as the DdPS-DGVAR model, without changing the lag orders of the individual country models. For this model, uncertainty with respect to the true lag orders of the country-specific models can then be allowed for by considering all possible combinations of lag orders for the DGVAR model with $p_{\max_i}$ and $q_{\max_i}$ not exceeding 1, given the limited availability of data. This yields four additional models, namely DdPS-DGVAR(p_i, q_i), for p_i, $q_i = 0$ and 1.

Additional GVAR models can be specified by dividing the countries into two groups, with Group A consisting of 10 industrialized countries plus China, and with the remaining 15 countries placed in Group B.[2] For Group A, the more developed economies, the lag orders and the number of co-integrating relations are set to those of the DdPS-GVAR model, while for the remaining less developed economies, zero co-integrating restrictions are imposed, reflecting the greater uncertainty regarding the true number of long-run relations for these countries. For Group B, uncertainty with respect to the lag order of the individual country/regions is also allowed, as above. These models are denoted by DdPS-GVAR$_{ab}$(p_i,q_i), for p_i, $q_i = 0$ and 1.

Another class of GVAR models can be developed from the long-run restricted specification in DHPS. The DHPS-GVAR model incorporates long-run structural relationships, suggested by economic theory, in an otherwise unrestricted GVAR model. DHPS show how the GVAR model needs to be modified in order for long-run relations such as purchasing power parity (PPP) to be imposed on the country-specific models, which include the effective exchange rate, amongst the domestic variables rather than the real exchange rate as in the GVAR. The long-term properties of this model are based on market arbitrage and stock-flow equilibrium conditions, while the short-run dynamics are left unconstrained. Using this specification, other long-run restricted models can be considered yielding 19 GVAR models overall, which are used in the forecasting exercise.

[2] Group A consists of US, euro area, China, Japan, UK, Canada, Australia, Sweden, Switzerland, Norway, and New Zealand, while Group B consists of India, Brazil, Mexico, Korea, Indonesia, South Africa, Argentina, Turkey, Thailand, Philippines, Saudi Arabia, Malaysia, Chile, Peru, and Singapore.

8.3.1 *Choice of observation windows*

This choice is restricted to some extent by the availability of data. For this reason, 10 quarterly estimation windows are selected, with the first window $W1$ starting in 1979q1, and ending up with window $W10$ starting in 1981q2. Further experimentation was conducted by increasing the space of models, as well as by selecting 10 bi-quarterly estimation windows beginning from 1979q1, with qualitatively similar results. The space of models and estimation windows considered are set out in Table 8.1.

Thus, the 19 different models within the GVAR family include two sets of GVAR models: five based on DHPS that impose over-identifying restrictions, and six based on DdPS that do not. The remaining specifications are simply variants of these models.

8.3.2 *Trade weights*

For in-sample estimation over the period 1979q1–2003q4 fixed trade weights are used averaged over the three-year window 1999–2001. For out-of-sample recursive forecasting trade weights are obtained as an average over 2001–2003 to compute the 2004 forecasts, and as an average over 2002–2004 to compute the 2005 forecasts. All country-specific models were estimated for the case of an unrestricted intercept and no trend. Only six out of 26

Table 8.1. Space of GVAR models and estimation windows.

Space of Models (19)	
DdPS-GVAR	DHPS-GVAR
DdPS-DGVAR	–
DdPS-DGVAR(0,0)	DHPS-DGVAR(0,0)
DdPS-DGVAR(0,1)	DHPS-DGVAR(0,1)
DdPS-DGVAR(1,0)	DHPS-DGVAR(1,0)
DdPS-DGVAR(1,1)	DHPS-DGVAR(1,1)
DdPS-GVAR$_{ab}$(0,0)	DHPS-GVAR$_{ab}$(0,0)
DdPS-GVAR$_{ab}$(0,1)	DHPS-GVAR$_{ab}$(0,1)
DdPS-GVAR$_{ab}$(1,0)	DHPS-GVAR$_{ab}$(1,0)
DdPS-GVAR$_{ab}$(1,1)	DHPS-GVAR$_{ab}$(1,1)
Beginning of estimation windows (10)	
W1:1979q1, W2:1979q2, . . . , W10:1981q2	

Note: The DHPS-DGVAR model is excluded from the above table since it coincides with the DHPS-GVAR$_{ab}$(1,0) model, given that the specification across all underlying individual country models in the case of DHPS-GVAR is a VARX*(2,1). See DHPS for further details.

countries rejected the null of co-trending, namely China, Japan, Argentina, New Zealand, India, and Turkey, at the 1% significance level.

8.4 Forecast evaluation: methodological considerations

There are eight one-quarter ahead forecasts (obtained over the period 2004–05) for each of the variables, per country, which is not sufficient for statistical testing of forecasts for individual countries. However, by pooling forecast errors for the same variable across different countries, a panel version of the Diebold and Mariano (1995, DM) model can be carried out, details of which can be found in Pesaran, Schuermann, and Smith (2009, PSS).

8.4.1 *Benchmark models*

The forecast performance of the GVAR model is compared to forecasts from random walk and AR(1) models, with and without drifts. The specifications of the four benchmark models are:

$$\text{Random walk } (RW): y_t = y_{t-1} + \varepsilon_t,$$
$$\text{Forecast } : y_{t+h|t} = y_t.$$

$$\text{Random walk } (RW) \text{ plus drift } \mu : y_t = \mu + y_{t-1} + \varepsilon_t,$$
$$\text{Forecast } : y_{t+h|t} = h\hat{\mu} + y_t,$$
$$\hat{\mu} \text{ is obtained by estimation of} : \Delta y_t = \hat{\mu} + \hat{\varepsilon}_t.$$

$$AR(1) : y_t = a + \gamma y_{t-1} + \varepsilon_t,$$
$$\text{Forecast } : y_{t+h|t} = \hat{a} + \hat{\gamma} y_{t+h-1|t}.$$

$$AR(1) \text{ plus trend} : y_t = a + \beta t + \gamma y_{t-1} + \varepsilon_t,$$
$$\text{Forecast } : y_{t+h|t} = \hat{a} + \hat{\beta} t + \hat{\gamma} y_{t+h-1|t}.$$

Although admittedly simple, the endurance of the above simple models as benchmarks stems from the fact that they have been surprisingly hard to beat.

8.4.2 *Pooling GVAR forecasts*

The estimation sample spans 1979q1–2003q4 for a total of 100 quarters (or 25 years). This is the same sample used to estimate the GVAR model presented in DdPS; indeed precisely that fitted model is used here for forecast evaluation to avoid being subject to data snooping. The new data sample goes through 2005q4, which gives eight quarters for out-of-sample forecast evaluation. For a given model of those presented in Table 8.1 above, each out-of-sample quarter is forecast with the maximum amount of data available. Specifically, 2004q1 is the out-of-sample forecast with data from 1979q1 to 2003q4. Next, 2004q2 is forecast by adding the realized first quarter (2004q1), and so on.

To allow for possible structural breaks, the estimation window is changed. Specifically, the start date of the estimation sample is moved forward by one quarter, and the process of out-of-sample forecasting is repeated as before. This denotes a new sample or estimation window. A total of 10 such samples from the longest to the shortest, in one quarter increments, are used so that the last estimation start date is at 1981q3; see Table 8.1. This estimation process is repeated for each of the 19 models. Thus for each out-of-sample forecast date, say 2004q1, there are 10 windows and 19 models yielding a total of 190 forecasts for each variable to be pooled or averaged. The average forecast over models for a particular estimation window is denoted by AveM, the average forecast from a particular model estimated over different estimation windows by AveW, and AveAve the average forecast over both models and estimation windows.

The benchmark forecasts are obtained by estimating the parameters of the benchmark models recursively over the longest window. Results for the benchmark forecasts based on other windows are very similar.

8.5 Forecast evaluation results

In what follows only a selected set of results based on one-quarter-ahead forecasts will be presented due to space constraints. More detailed results can be found in PSS. Figures 8.1–8.3 display the average of the root mean-squared forecast error (RMSFE), in per cent, for output, inflation, and short-term interest rates of the GVAR model across the 10 industrialized countries plus China. In these figures, the horizontal axis shows the 10 windows from longest to shortest. The circles on the vertical lines associated with a particular window show the RMSFE related to the GVAR and the stars show that related to the DGVAR model forecasts estimated over the corresponding window. The AveAve forecast is given by the horizontal line and dominates all other forecasts when all the circles and stars lie above the line.

The AveAve forecasts seem to do particularly well in the case of these variables. Only a few of the specific models/windows do better than the AveAve forecasts. Moreover, the models and windows that do better were found to not be the same across the countries. The results for other variables were less clear-cut but overall favoured the use of the AveAve strategy. The AveAve forecasts were found to do best for the 10+China grouping, when

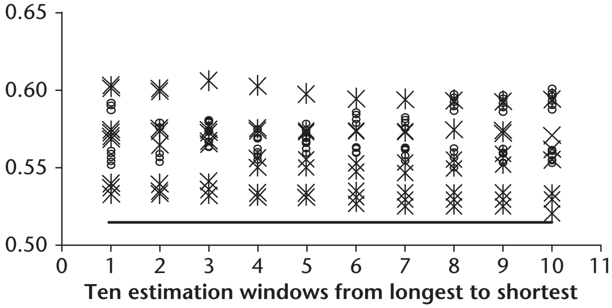

Figure 8.1. Average RMSFEs of one-quarter ahead forecasts for real output growth.

Note: The root-mean-squared forecast error (RMSFE) of a given model is computed as $RMSFE(h,n) = 100\sqrt{n^{-1}\sum_{t=T}^{T+n-1} e_t^2(h)}$, for $h = 1$ and $n = 8$, where h is the forecast horizon, n is the size of the forecast evaluation sample, $e_t(h) = y_{t+h} - \hat{y}_{t+h|t}$ is the h-quarter ahead forecast error, y_{t+h} is the actual value, and $\hat{y}_{t+h|t}$ is the corresponding forecast formed at time t. The average RMSFE is for the 10 industrialized countries plus China. The circles on the vertical lines associated with a particular window show the GVAR and the stars show the DGVAR model forecasts estimated over that window. The AveAve forecast is given by the horizontal line.

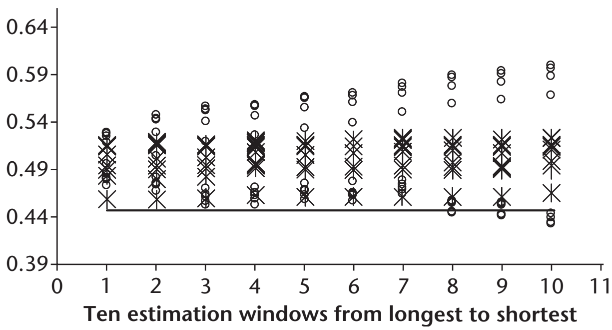

Figure 8.2. Average RMSFEs of one-quarter ahead forecasts for inflation.

compared to the other two regional groupings (All without Latin America (LA) and All Countries).

The AveAve forecasts from the GVAR were in general better than forecasts from a single GVAR model estimated over a single observation window. These forecasts also tended to perform better than the AveM forecasts computed as averages of forecasts from different models all estimated on a single window, or AveW forecasts computed as averages of the forecasts obtained from the same model estimated across different windows. In particular, the AveAve forecasts were found to do better than the GVAR models specified in DdPS (2007) and DHPS (2007) when the forecasts of the latter are averaged

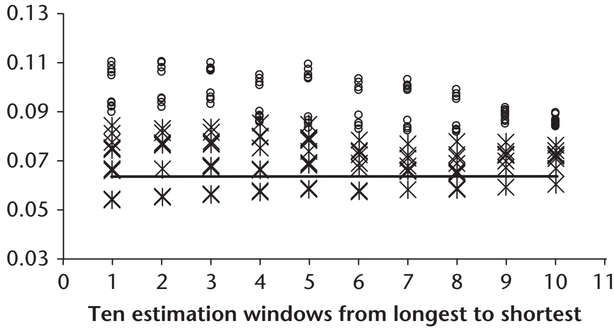

Figure 8.3. Average RMSFEs of one-quarter ahead forecasts for short-term interest rate.

across the 10 windows. The same was true when the AveAve forecasts were compared to the AveM forecasts.

8.5.1 *Performance of AveAve forecasts relative to the benchmarks*

A summary figure is provided to illustrate the performance of the AveAve forecasts relative to the benchmark models. Figure 8.4 shows for each of the three country groupings the proportion of forecasts where the AveAve forecast beats the benchmarks at the 95% confidence level or better. Since there are four benchmarks, the best the GVAR-AveAve forecasts can do is four out of four, with the overall performance index set at 100%. If the GVAR-AveAve forecasts were beaten by all the benchmarks, the performance index would take the value of −100%. Nothing is recorded in the figure if the differences between the AveAve and the benchmark forecasts are not statistically significant. For each variable, when the AveAve model does better (in the panel DM sense), the bars are in the positive region; when a benchmark competitor does better, the bars are in the negative region. Of course, it is possible that the AveAve can beat some models and lose to others.

Beginning with the first set of bars on the left of Figure 8.4, none of the benchmark forecasts do better than the GVAR-AveAve in forecasting output growth, and based on the panel DM test the GVAR-AveAve forecasts significantly beat half of the benchmark models for 10+China country group, and beat three of the four benchmark forecasts when all countries, with or without Latin America, are considered. Moving on to the next variable, inflation, the AveAve performance is as good overall and significantly better in the case of the industrialized economies, beating three out of four benchmarks for the 10+China country group. Similar results are obtained for the All excluding LA country grouping. In this case, the GVAR-AveAve inflation

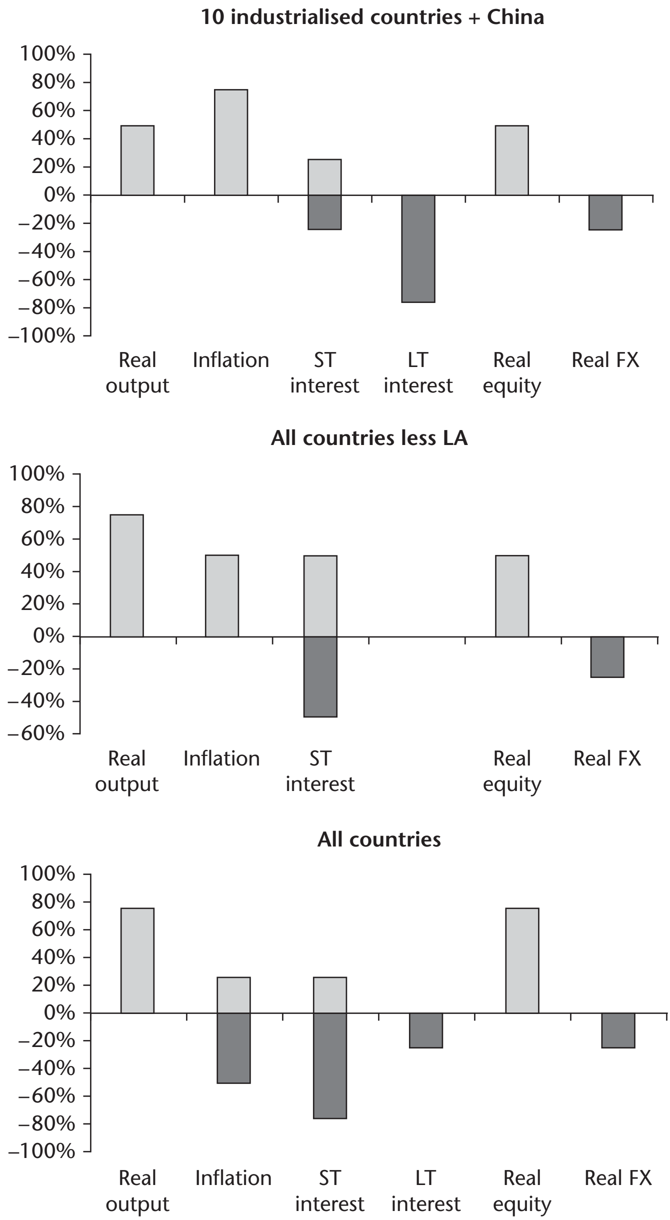

Figure 8.4. Performance of AveAve forecasts based on GVAR models versus the forecasts from the four benchmarks—% of forecast where GVAR-AveAve beats benchmark at 95% CI or better.

Note: In the case of the long-term interest rate only the grouping 'All Countries' is relevant, which comprises 12 countries, non of which belong to the Latin America (LA) region.

forecasts significantly beat two of the benchmark forecasts without being beaten by any of the benchmarks.

The situation, however, is mixed when the Latin American countries are included in the comparison. The AveAve forecasts continue to do better than two of the benchmarks, but are significantly beaten by the two random walk benchmarks. Several of the Latin American countries experienced a period of hyperinflation during the estimation sample, and so perhaps it is not surprising that the GVAR cannot forecast inflation in these countries over the 2003–05 period with a more moderate inflationary experience.

Interest rates turn out to be harder to forecast. Indeed, the random walk benchmark does better than the AveAve forecasts for all country groupings. Taking the short-term rate of interest, for the panel of industrialized countries plus China, the AveAve forecast is significantly better than the AR(1) with trend, but when looking at the All excluding LA group, the AveAve forecast does better than half of the benchmark models (it beats the AR(1) models). When all the countries are included, the GVAR-AveAve forecast only beats the AR(1) benchmark, while the three other benchmarks all do statistically better. For the long-term interest rate, the AveAve forecast is never better than any of the benchmark models.

Not surprisingly it is much harder to accurately forecast real equity prices and exchange rates as compared to forecasting output, inflation, and interest rates. Nevertheless, it is interesting that the GVAR-AveAve forecasts of real equity prices perform significantly better than several of the benchmark forecasts—three ('All countries') and two (the other two groupings) of four—and are not beaten significantly by any of the four benchmarks, including the RW specifications.

Finally, the fact that sometimes simple models do better than the GVAR is not really that helpful, since different alternative models win for different variables, and one would not necessarily know which one would do so a priori.

8.5.2 *The relevance of capital markets in forecasting output, inflation, and the short-term interest rate*

To assess the role that capital markets might play in forecasting output, inflation, and the short-term interest rate, the same forecasting exercise as described above is carried out, entertaining the following two modified sets of DdPS-GVAR and DHPS-GVAR models. The first set consists of the GVAR models with the equity variable dropped from all country-specific models, while a second set excludes both the real equity and long-term interest rate variables from all the country-specific models. In carrying out this exercise, the five Latin American countries are excluded from the GVAR models in order to avoid any predominant effects related to the distinctive behaviour of these economies over the period under investigation (notably the very high inflation rates experienced during the 1980s) that could potentially overshadow the aim of the exercise. Thus, for all results relating to this exercise the DdPS-GVAR and DHPS-GVAR models and their variants comprise of 21 country/regions.

The space of models and selection of estimation windows are the same as in the previous experiments. Similarly, in obtaining the quarterly forecasts for 2004 and 2005, the individual country models are estimated for the case of an unrestricted intercept and no trend, following results of the co-trending tests, with the trade-weights adjusted as described earlier. However, dropping countries or variables from the GVAR gives rise to a new model, which means that the lag orders and number of co-integrating relations for the individual country models need to be re-estimated. All these exercises are carried out with the samples ending in 2003q4.

Table 8.2 shows the panel DM statistics for the one-quarter-ahead forecasts to test whether the differences between the three specifications are in fact statistically significant. The results for all three variables do not show evidence that including the financial variables (equity prices and the long rate) contributes substantively to the forecast accuracy of output, inflation,

Table 8.2. Panel DM statistics for AveAve forecasts of the GVAR model over the period 2004q1–2005q4, excluding Latin America.

Models	$z_{ijt} = [e^A_{ijt}(1)]^2 - [e^B_{ijt}(1)]^2$	
	10 Industrialized Plus China	All Countries
Real output		
Without EQ	0.480	−0.823
Without EQ & LR	0.674	−0.227
Inflation		
Without EQ	−1.497	1.223
Without EQ & LR	0.274	0.496
Short-term interest rate		
Without EQ	0.557	−0.744
Without EQ & LR	0.744	0.145

Note: $e^A_{ijt}(1)$ denotes the forecast error corresponding to the one-quarter ahead AveAve forecast of the GVAR model that includes equity and the long-term interest rate; $e^B_{ijt}(1)$ denotes the forecast error corresponding to the one-quarter ahead AveAve forecasts based on the GVAR model excluding real equity prices (without EQ), and a GVAR model that excludes both the real equity prices and the long-term interest rates (without EQ & LR). The group All countries for this set of results comprises 21 countries (Latin American countries are excluded from this version of the GVAR model) for real output and inflation and 20 countries for the short-term interest rate (since no interest rate data is available for Saudi Arabia). For a one-sided test, which is appropriate here, the 1% and 5% critical values are −2.326 and −1.645, respectively. A positive value of the panel DM statistic represents evidence against the AveAve forecasts of the GVAR model that includes equity and the long-term interest rate.

or the short rate. The panel DM statistics show that none of the differences for the one-quarter-ahead forecast are statistically significant. In country-specific results not presented here, US and Canada showed evidence of the relevance of long rates for forecasting output, though this was not the case for other countries. Perhaps financial variables contributed little to forecast accuracy, since our evaluation period coincided with a rather quiet period in the financial markets. In more turbulent times they may contain more information and could result in improved forecasts.

8.5.3 *Additional forecast comparisons*

By adding data from 2006q1 to 2006q4, with 12 quarters out-of-sample, the models presented above were re-evaluated based on the same model specifications, where as before the model parameters were updated recursively every quarter. The main results, based on just eight quarters out-of-sample, were unchanged by the addition of another four quarters. If anything, they were strengthened. Forecasts of the individual country GVAR models can be computed using the GVAR Toolbox 2.0 of Smith and Galesi (2013).

8.6 Conclusions

In this chapter the basic GVAR model was examined and evaluated with regard to its forecasting ability. Out-of-sample one- and four-quarter-ahead forecasts of real output, inflation, and a number of financial variables over the period 2004q1–2005q4, were generated. The forecasts were compared with univariate autoregressive and random walk models. It was found that when GVAR forecasts are averaged over both different model specifications and different estimation windows (the ‘AveAve’ forecasts), the results tend to outperform forecasts based on individual models, especially for output and inflation. When compared to the benchmark models, the GVAR-based AveAve forecasts were superior in the case of output and inflation. The results were mixed for the short-term interest rates and other variables where in general the AveAve did as well as, though in some cases worse than, the benchmark forecasts. While it was found that the inclusion of long-term interest rates and real equity prices does indeed help improve forecasts of real output and inflation in the case of some advanced economies, particularly the US and Canada, this is not the case more generally.

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9

Nowcasting quarterly euro-area GDP growth using a global VAR model*

Silvia Lui and James Mitchell

9.1 Introduction

Statistical offices publish their GDP data at a lag. For example, Eurostat publishes its so-called Flash estimate of quarterly GDP growth for the euro-area (EA) about 45 days after the end of the quarter. This publication delay is seen to hinder decision- and policy-making given the need for an accurate, but timely, impression of the state of the economy. As a result, there is always pressure on statistical offices to speed up the delivery of these estimates. Inevitably, with resource constraints impeding the production of earlier and/or higher-frequency official quantitative surveys, this means relying increasingly on forecasting. Or, more accurately, this should be called 'nowcasting'—as within-quarter information on indicator variables is exploited. But there is an expected trade-off between the timeliness and accuracy of nowcasts. Nowcasts can always be produced more quickly by exploiting less information; but we might expect the quality of the nowcasts to deteriorate as a result. It is therefore imperative to quantify empirically the nature of the trade-off, and evaluate the reliability of nowcasts produced at particular time horizons.

Increasing attention has therefore been given in recent years to the production of nowcasts, as opposed to forecasts. Nowcasts, as we summarize further below, can be computed using many different modelling approaches; these include bridge models, factor models, mixed-frequency state-space models, multivariate models, and MIDAS models, *inter alia*. See

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Banbura et al. (2012) for a review. What these approaches share in common is their emphasis on exploiting cross-variable dependencies; in particular, the nowcasts are constructed by exploiting information on so-called indicator variables. These are variables that are meant to have a close relationship with GDP, or whatever the series of interest happens to be, but are made available more promptly than the data for which they stand as a proxy.

Our point of departure is to consider, specifically, the construction of nowcasts for contemporaneously aggregated variables, such as euro-area GDP growth, accommodating cross-country as well as cross-variable dependencies. While cross-country dependency has received considerable attention when forecasting aggregates (e.g. Lütkepohl, 1984; Granger, 1987; Giacomini and Granger, 2004; and Pesaran et al., 2009; the latter in fact using a GVAR), nowcasts of aggregates, like EA GDP growth, have tended to be produced in one of two ways, both of which ignore cross-country dependencies.

Firstly, and most commonly, nowcasts have been computed at the aggregate level, with an aggregate model adopted and an aggregate nowcast produced directly by conditioning on aggregate indicators and/or lags of the aggregate itself. This is the so-called 'direct' approach. It has been used in various applications to EA GDP growth, including by Rünstler and Sedillot (2003), Sedillot and Pain (2003), Diron (2008), Giannone et al. (2009), and Angelini et al. (2011). Secondly, the nowcasts are produced at a disaggregate level (the so-called 'indirect' approach) using a disaggregate model, which conditions on disaggregate information, and are then aggregated up to produce a nowcast for the aggregate. This is in fact the approach Eurostat takes itself when producing their Flash estimates; see Eurostat (2003). This focus on the direct and indirect approaches is, however, at odds with both the perception that cross-country dependencies have increased due to 'Europeanization', if not globalization (i.e. common factors drive international co-movements), and the fact that publication lags for official data vary across countries. This latter fact is especially important in a nowcasting, as opposed to forecasting, context. Some countries, as discussed below, publish their data more quickly than others, and indeed more quickly than Eurostat publishes the corresponding aggregate. Known disaggregate data can therefore be exploited when nowcasting the unknown aggregate; cf. Hendry and Hubrich (2011).

In this chapter, we therefore empirically compare the performance of direct and indirect nowcasts of EA GDP growth with those constructed using a global VAR model (strictly, a European VAR model), as proposed by Pesaran et al. (2004), which allows for both cross-country and cross-variable dependencies. The GVAR model, as we review, offers a computationally convenient and feasible means of producing nowcasts of aggregates like EA GDP growth from large disaggregate data sets, via a multivariate model, which can capture any dependencies. Our particular focus is the construction of nowcasts for EA GDP growth 30 days after the end of the quarter, which is 15 days earlier than Eurostat's own Flash estimate. Our results should help build an empirical consensus about which approach is best; to date evidence from empirical studies has been, to some degree, mixed; e.g. while Marcellino et al. (2003) and Baffigi et al. (2004) find that aggregating national forecasts delivers better GDP forecasts than forecasts constructed using the aggregate data, in the context of forecasting industrial production Bodo et al. (2000) find the reverse. In a longer companion paper, Lui and Mitchell (2012) also consider the use of the GVAR to produce nowcasts. But to quantify the putative trade-off between timeliness and accuracy they consider nowcasts of quarterly GDP, not just 30 days after the end of the quarter but as within-quarter (monthly) information on indicator variables accrues. They also detect, and analyse, clear instabilities in nowcast performance; with the proposed GVAR nowcasts becoming more competitive than the direct and indirect approaches over the 2008–9 recession as cross-sectional dependence between the EA countries increased.

The plan of this chapter is as follows. Section 9.2 considers the production of nowcasts, distinguishing the direct and indirect approaches. Section 9.3 explains how the GVAR can be used in nowcasting contexts. Section 9.4 is an application of the direct, indirect, and GVAR models to nowcasting EA GDP growth. Section 9.5 concludes.

9.2 Nowcasting models

9.2.1 *Indicator variables*

Nowcasts are typically produced by statistical models. These statistical models by construction, and unlike structural or economic models, are reduced-form. They seek to explain and then nowcast GDP growth by exploiting information on indicator variables. These are variables, as discussed above, which are meant to have a close relationship with GDP but are made available more promptly; moreover, often these indicators are published at a higher frequency (e.g. monthly) than GDP itself, which is typically published on a quarterly basis only. In practice, there is a large set of potential indicator variables, both quantitative ('hard') and qualitative ('soft'), with hard data typically published later than the soft data. But the cost of the timeliness of soft data is their qualitative nature. The set increases further when, as possible indicators, we consider variables not directly related to GDP but presumed to have some indirect relationship. For example, interest rates or exchange rates might be considered, as they might help predict GDP growth.

9.2.2 *The modelling approach*

Since current and lagged values of these indicator variables, and lags of GDP itself, can plausibly help explain current-quarter GDP one must consider carefully how one selects the indicator variables for the model used to explain GDP growth. The number of possible indicator variables can easily get very large. The problem is then to either 'select', in some sense, the 'best-fitting' indicators (these best-fitting indicators can be chosen on the basis of both a priori or objective in-sample performance criteria) or 'reduce' the set of indicator variables 'automatically'. Once this is done, the models that can be used to nowcast GDP growth are estimable using classical statistical methods—there are no degrees-of-freedom constraints. Different models involve different ways of linking the indicator variables to GDP. This can be done at a quarterly, monthly, or mixed frequency. It is an empirical question, which is most sensible.

Here we consider forecasting quarterly GDP growth using regression-based bridge models, with a small number of indicator variables. An alternative is to nowcast and forecast monthly GDP using mixed-frequency regression, VAR, or factor-based methods, which impose an aggregation constraint so that monthly GDP is consistent with the published quarterly values (e.g., see Mariano and Murasawa, 2003; Mitchell et al., 2005; Angelini et al., 2010; Angelini et al., 2011; Banbura and Rünstler, 2011). Bayesian estimation methods, exploiting the Kalman filter and 'skipping' missing observations, and MIDAS models (e.g. see Kuzin et al., 2011) also offer alternative means of linking mixed-frequency data.

The regression-based approach focuses on a small set of indicator variables that bear a close relationship to GDP. Its attraction is that it is simple and easy to interpret. It is designed to comply with the criterion that the models used to produce nowcasts should be credible to policymakers and other non-statisticians. We also see this as ruling out high-order dynamic models, whereby GDP growth is affected by historical movements in exogenous variables, since it is difficult for a statistics office (the putative producer of our nowcasts) to defend a situation where current-quarter GDP is sharply influenced, for example, by movements in some indicator variable many months ago. (A professional forecaster, on the other hand, may have no difficulty in explaining the economic transmission mechanism.)

9.2.2.1 MONTHLY BRIDGE EQUATIONS

Bridging involves linking monthly indicator data, typically released early in the quarter, with quarterly data like GDP; e.g. see Salazar and Weale (1999), Baffigi et al. (2004), and Diron (2008). In effect, a two-equation system is used to nowcast, with the first equation containing GDP growth augmented with a second equation comprising the forecasting model for the monthly indicator variable(s). The errors between the two equations, at the underlying monthly frequency, are assumed orthogonal so that the equations are estimated separately. In common with much previous work, (see Diron, 2008), we experimented with simple monthly AR models to forecast any missing monthly indicator data. In fact, we found no loss in accuracy in using a random walk (i.e. a restricted AR) forecast and therefore focus on its use in the application below.

In effect, the first equation can be seen to come from a quarterly VAR model in $\mathbf{x}_{it}$, where $\mathbf{x}_{it}$ denotes a k-dimensional vector that contains the domestic variables of country i ($i = 1, \ldots, N$) at quarter t ($t = 1, \ldots, T$). In principle, k might vary across i, but here we assume $k_i = k$. More specifically, let $\mathbf{x}_{it}$ contain the variable of interest, GDP growth, plus a $(k-1)$ vector of indicator variables for each country, i, denoted $\mathbf{x}_{it}^{Ind}$. It is these indicator variables that are possibly available at the monthly frequency. Variables are differenced until stationary. Then we write the quarterly nowcasting model, in general form, as

$$\mathbf{x}_{it} = \Theta_{ii}\mathbf{x}_{it-1} + \mathbf{u}_{it} \tag{9.1}$$

where one lag is assumed for notational ease only; and deterministic terms (such as intercepts and time-trends) are also ignored. The idiosyncratic shocks, $\mathbf{u}_{it}$, are assumed serially uncorrelated with mean $\mathbf{0}$ and a non-singular covariance matrix, Σ_{ii}. It is via Σ_{ii} that GDP growth in country i at quarter t depends contemporaneously on $\mathbf{x}_{it}^{Ind}$. Assuming multivariate normality of $\mathbf{u}_{it}$ and substituting the equations for $\mathbf{x}_{it}^{Ind}$ into the equation for GDP growth, we obtain the nowcasting model in its more traditional (single-equation) conditional form, which is estimated by regressing GDP growth at quarter t on quarter t values of $\mathbf{x}_{it}^{Ind}$ and lagged values of $\mathbf{x}_{it}^{Ind}$ and GDP growth.

Equation (9.1), more commonly seen in its conditional singe-equation counterpart, is then estimated in-sample ($t = 1, \ldots, T$). Nowcasts for quarter $(T+1)$ are then obtained out-of-sample using $\widehat{\mathbf{x}}_{iT+1}^{Ind}$, where $\widehat{\mathbf{x}}_{iT+1}^{Ind}$ denotes the forecast of the indicators $\widehat{\mathbf{x}}_{iT+1}^{Ind}$ made using available monthly data. Depending on how long after the end of the quarter T the nowcasts for $(T+1)$ are produced, some of the indicators may, in fact, be known for the whole quarter $(T+1)$. There is, therefore, then no need to forecast them. For other indicators, partial within-quarter monthly data are available and only one or two months within quarter $(T+1)$ need to be forecast. For example, when nowcasting GDP growth 30 days after the end of quarter T, in euro-area countries qualitative survey data are available for all three months of quarter $(T+1)$ but only two months of data on industrial production

(IP) are available (except for Portugal, where all three months' data are at hand); the final month in quarter $(T+1)$ for IP is therefore forecast when not yet published. This forecasted value for IP is then combined with the two months of hard data to obtain the quarterly forecast for IP, which forms an element of $\widehat{\mathbf{x}}_{iT+1}^{Ind}$, along with the known qualitative survey data for quarter $(T+1)$.

9.2.2.2 THE DIRECT AND INDIRECT APPROACHES

Our objective is to nowcast the aggregate $\sum_{i=1}^{N} w_i \mathbf{x}_{iT+1}$, where w_i is a set of weights $\left(\sum_{i=1}^{N} w_i = 1\right)$, discussed below, conditioning not just on $\mathbf{x}_{iT}$ but on $\widehat{\mathbf{x}}_{iT+1}^{Ind}$ too $(i = 1, ..., N)$. This is most commonly achieved using the direct and/or indirect approaches.

The indirect (or disaggregate) approach involves first estimating, separately for each country i, the conditional equation counterpart of the disaggregate model (9.1), which relates GDP growth in country i at quarter t to the $(k-1)$ vector of indicators for country i, $\mathbf{x}_{it}^{Ind}$ $(t = 1, ..., T)$, plus their lags. It then aggregates up the nowcasts across i to produce a nowcast for the aggregate

$$\sum_{i=1}^{N} w_i E\left(\mathbf{x}_{iT+1} \mid \widehat{\mathbf{x}}_{iT+1}^{Ind}, \mathbf{x}_{iT}\right). \tag{9.2}$$

The direct (or aggregate) approach involves producing nowcasts directly from an aggregate model. If the disaggregate models are VAR(MA) models, then the aggregate model in $\sum_{i=1}^{N} w_i \mathbf{x}_{it}$ is, in fact, also a VAR(MA) model; see Lütkepohl (1984). Having estimated the aggregate model, the nowcast is computed directly from it as

$$E\left(\sum_{i=1}^{N} w_i \mathbf{x}_{iT+1} \,\middle|\, \left\{\sum_{i=1}^{N} w_i \widehat{\mathbf{x}}_{iT+1}^{Ind}, \sum_{i=1}^{N} w_i \mathbf{x}_{iT}\right\}\right). \tag{9.3}$$

Neither of these approaches accommodate cross-country dependencies. Accommodating these dependencies might be especially felicitous when nowcasting, given that different countries publish their data to different time-scales. It is therefore possible to condition the nowcast for the aggregate on known or partially known, rather than forecasted, quarterly disaggregate information. This means, as discussed below, that 30 days after the end of the quarter T one can condition the aggregate nowcast on known country-level quarter $(T+1)$ GDP data for those countries, like Belgium and Spain, who currently publish their GDP data within 30 days, as well as Portuguese IP, since it is also known for all three months of quarter $(T+1)$.

9.3 Nowcasting using the GVAR

To accommodate cross-country dependencies, as well as cross-variable dependencies, when nowcasting we consider a global (or generic high-dimensional multivariate) model.[1] Stacking (9.1) across i, the global linear autoregressive model in the kN-vector $\mathbf{x}_t = (\mathbf{x}'_{1t}, \mathbf{x}'_{2t}, \ldots, \mathbf{x}'_{Nt})'$ is given as

$$\mathbf{x}_t = \Theta \mathbf{x}_{t-1} + \mathbf{u}_t \tag{9.4}$$

or, less compactly,

$$\begin{bmatrix} \mathbf{x}_{1t} \\ \mathbf{x}_{2t} \\ \vdots \\ \mathbf{x}_{Nt} \end{bmatrix} = \begin{bmatrix} \Theta_{11} & \Theta_{12} & \cdots & \Theta_{1N} \\ \Theta_{21} & \Theta_{22} & \cdots & \Theta_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \Theta_{N1} & \Theta_{N2} & \cdots & \Theta_{NN} \end{bmatrix} \begin{bmatrix} \mathbf{x}_{1t-1} \\ \mathbf{x}_{2t-1} \\ \vdots \\ \mathbf{x}_{Nt-1} \end{bmatrix} + \begin{bmatrix} \mathbf{u}_{1t} \\ \mathbf{u}_{2t} \\ \vdots \\ \mathbf{u}_{Nt} \end{bmatrix} \tag{9.5}$$

where one lag is assumed for notational ease only, and deterministic terms are again ignored. The idiosyncratic shocks, $\mathbf{u}_{it}$, are assumed serially uncorrelated with mean $\mathbf{0}$ and a non-singular covariance matrix, Σ_{ii}, with Σ denoting the covariance matrix of $\mathbf{u}_t$, with $k \times k$ submatrices Σ_{ij} $(i, j = 1, \ldots, N)$ denoting the covariance matrices of $\mathbf{u}_{it}$ and $\mathbf{u}_{jt}$. This global model allows for cross-country, as well as cross-variable, interactions. Cross-country (dynamic) dependence is captured via Θ_{ij} $(i \neq j)$ and contemporaneously via the dependence of the shocks of country i on the shocks of country j, i.e. Σ_{ij}, $i \neq j$.

Our aim is to use (9.4) to forecast, or more strictly nowcast, the aggregate $\sum_{i=1}^{N} w_i \mathbf{x}_{it}$. To produce such a nowcast requires estimation of (9.4).

But classical estimation of the parameters in (9.4), as a system, is feasible only if N is small. This dimensionality problem when N is large can be resolved by shrinking the parameter space and/or reducing the size of the data set. The former is often achieved by imposing priors and estimating the (large-dimensional) VAR using Bayesian methods (a BVAR); e.g. see Banbura et al. (2010). Giacomini and Granger (2004) restrict the degree of interdependence across i in (9.4) by proposing spatial autocorrelation models. Factor methods are the most widespread means of reducing the size of the data set. Below we follow Chudik and Pesaran (2011) and deal with this curse of dimensionality by effectively shrinking the parameter space in the limit as the number of endogenous variables (N) tends to infinity. This

[1] Alternatively, a mixed approach has been proposed by Hendry and Hubrich (2011), in which an aggregate forecast is produced by conditioning on both the aggregate and disaggregate indicators. This, like the GVAR model, offers in theory a means of constructing more efficient nowcasts, since the aggregate is conditioned on a larger information set.

infinite-dimensional VAR, as Chudik and Pesaran (2011) explain, can then be arbitrarily well approximated by a set of finite-dimensional small-scale models that can be consistently estimated separately as a global VAR (GVAR) model, as proposed in Pesaran et al. (2004). We consider the GVAR further in Section 9.3.1 below. Giannone and Reichlin (2009) discuss the relationship between the BVAR and GVAR approaches.

Absent estimation uncertainty, conditioning the aggregate nowcast on all available disaggregate information, via (9.4), is root mean squared error (RMSE) prediction error minimizing. The direct, (9.3), and indirect, (9.2), approaches are, in general, inefficient, given that they do not accommodate all of the cross-variable and cross-country dependencies. The indirect approach is a special case of the global model, (9.4), when $\Theta_{ij} = 0$ and $\Sigma_{ij} = 0$ for all $i \neq j$. Giacomini and Granger (2004) detail the RMSE gain of the multivariate model relative to the direct and indirect approaches. When there is a significant common factor that explains the correlation across i, there can be gains to using disaggregated models provided the common factor is taken into account, which it is not in (9.1), since the process for the aggregate is dominated by the common factor; cf. Granger (1987). See also Taylor (1978) on when, in theory, we might expect performance to vary across the direct, indirect, and global models. The relative gain in efficiency of conditioning the aggregate forecast on all disaggregate components (i.e. using a multivariate model) is likely large when there is a high degree of heterogeneity in the disaggregate series being aggregated. When the disaggregate series are highly correlated, the relative gain in efficiency is likely low. When the disaggregate series exhibit common variation (e.g. there is a common factor that explains all of their variation) then the direct, indirect, and global approaches merge; see Taylor (1978). And, as seen, when there is heterogeneity across countries but $\Theta_{ij} = 0$ and $\Sigma_{ij} = 0$ for all $i \neq j$, the multivariate approach reduces to the indirect approach.

But the relative performance, in terms of RMSE, of the different approaches is, in practice, given estimation error, an empirical matter.

9.3.1 *Global VAR models*

The GVAR model developed by Pesaran et al. (2004), Dées et al. (2007), and Pesaran et al. (2009) facilitates estimation of (9.4) by viewing (9.4) as a reduced-form based on N country-specific VAR models in $\mathbf{x}_{it}$, with international linkages captured by relating $\mathbf{x}_{it}$ to their corresponding foreign variables, $\mathbf{x}^*_{it}$, defined below. Estimation then proceeds in two steps. First, estimate by OLS N VARX* models for each country to obtain the parameter matrices in the country-specific models. The GVAR in the endogenous variables $\mathbf{x}_{it}$ is then solved for simultaneously by using a 'link' matrix that contains the predetermined weight for each country and the parameter matrices in the N VARX* models.

Specifically, consider a VARX* model for country i ($i = 1, \ldots, N$), again assumed to be first-order and ignoring deterministic terms,

$$\mathbf{x}_{it} = \Phi_{i0}\mathbf{x}_{it-1} + \Lambda_{i0}\mathbf{x}^*_{it} + \Lambda_{i1}\mathbf{x}^*_{it-1} + \mathbf{u}_{it}, \tag{9.6}$$

where $\mathbf{x}^*_{it}$ is a $k^* \times 1$ vector containing the foreign variables. These foreign variables can be seen to capture the effect of common factors; cf. Pesaran (2006). $\mathbf{x}^*_{it}$ vary by country i and are defined as

$$\mathbf{x}^*_{it} = \sum_{j=1}^{N} w_{ij}\mathbf{x}_{jt};\ w_{ii} = 0, \tag{9.7}$$

with the predetermined weights w_{ij} capturing the importance of country j for country i. When, as in the application below, $\mathbf{x}^*_{it}$ are not clearly weakly exogenous, then consistent estimation of (9.6) is best approached by first estimating, for each country i, a $(k + k^*) \times 1$ dimensional VAR in $\mathbf{z}_{it} = (\mathbf{x}'_{it}, \mathbf{x}^{*'}_{it})'$ and then, at a second step, using these parameter estimates to solve for the parameters of the conditional model, as seen in (9.6). Given our nowcasting focus and desire to use statistical rather than economic models, the VAR is estimated using stationary data (i.e. data are differenced until stationary) and any long-run, co-integrating, restrictions are therefore ignored.

Since the domestic variables $\mathbf{x}_{it}$ are related contemporaneously to the foreign variables $\mathbf{x}^*_{it}$, which are themselves related to $\mathbf{x}_{jt}$ via the weights (or links) (9.7), the country-specific VAR models (9.6) need to be solved simultaneously for the GVAR in all of the endogenous domestic variables $\mathbf{x}_{it}$ ($i = 1, \ldots, N$). This can be achieved following Pesaran et al. (2004) and Dées et al. (2007). It delivers the GVAR of the generic form

$$\mathbf{x}_t = \mathbf{A}\mathbf{x}_{t-1} + \mathbf{B}\mathbf{u}_t, \tag{9.8}$$

with $\mathbf{A}$ and $\mathbf{B}$ defined as in Pesaran et al. (2004) and Dées et al. (2007).

Having estimated the N VARX* models, and having solved for the GVAR, nowcasts are computed from (9.8) by computing the expectation of $\mathbf{x}_{T+1}$ (specifically, the GDP growth elements of $\mathbf{x}_{T+1}$) conditional on $\widehat{\mathbf{x}}^{Ind}_{iT+1}$ and lags of $\mathbf{x}_T$. This is conveniently achieved by casting the GVAR in state-space form; and using SsfPack in Ox to compute the relevant conditional expectations using the Kalman filter and smoother. Thereby, since the Kalman filter can readily skip missing data, one can handle 'ragged-edges' in $\widehat{\mathbf{x}}^{Ind}_{iT+1}$, reflecting the differing publication lags across the EA12 countries. Nowcasts for the aggregate, EA GDP growth, are then obtained by taking the weighted average of these conditional expectations for GDP growth across the individual countries, with the weights, w_{ij}, given by their GDP shares (in the aggregate) over a (fixed) pre-nowcasting period. Given our application, these GDP share weights seem more appropriate than trade weights, as suggested by Pesaran et al. (2004) and Pesaran et al. (2009).

9.4 Application nowcasting euro-area GDP growth at $t + 30$ days

There is an expected trade-off between the timeliness and accuracy of nowcasts. Nowcasts can always be produced more quickly by exploiting less information, but we might expect the quality of the nowcasts to deteriorate as a result. We focus, in this chapter, on producing nowcasts of quarterly GDP growth for the EA(12) at $t + 30$ days, where t still denotes quarter, so that $t + 30$ means that a nowcast for quarter t is produced 30 days after the end of the quarter for which we want a quarterly GDP estimate. In contrast, Eurostat produce the first official estimate for GDP growth, their so-called Flash estimate, at $t + 45$ days. In Lui and Mitchell (2012) we produce and evaluate nowcasts at other time horizons too. But $t + 30$ days is of particular interest, since it is when the US produce their *advance* estimate of GDP. Focus on the EA(12) (i.e. $N = 12$) means the 12 countries comprising the aggregate are Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, and Spain.

At $t + 30$ days, GDP data for quarter t are (currently) available for Belgium and Spain. The GVAR therefore conditions on these data both when nowcasting GDP for the other countries and when aggregating the 12 disaggregate (country-level) GDP nowcasts. The indirect approach uses the hard data for Belgium and Spain only when aggregating, but not when nowcasting GDP in the other countries. The majority of the other countries in the EA produce their GDP estimates more slowly, after about 45 days, in line with Eurostat's Flash estimate for EA GDP, and hence their GDP data needs to be nowcast at $t + 30$ days.

9.4.1 *Indicator variables*

Following previous work (Mazzi et al., 2012; Lui and Mitchell, 2012) we focus on a parsimonious set of indicator variables. The approach here could be readily extended to consider a wider range of indicators. Specifically, we consider (aggregate and disaggregate, i.e. country-level) industrial production data as a 'hard' indicator for GDP growth. As a component of GDP, but available on a monthly basis, we should expect movements in industrial production to be informative about GDP growth. At 30 days after the end of the quarter, given industrial production data are published for the EA and its constituent countries with about a 45-day lag (the notable exception is Portugal, where estimates are available earlier at $t + 30$ days; see Lui and Mitchell (2012) for details on the publication lags), only the third month of the quarter (for industrial production) needs to be forecast using the monthly random walk model. Inaccurate forecasts of one month may nevertheless deliver reasonably accurate projections of the quarter to which they belong. For Portugal there is no need to forecast, at $t + 30$ days, and the published industrial production data for quarter $(T + 1)$ are used.

As additional ('soft') indicators we consider qualitative survey data, again at the aggregate and disaggregate levels. A perceived attraction of these surveys is that they are forward-, as well as backward-looking. They are also published at the end of the month to which they relate; so that 30 days after the end of the quarter, these data are known for the three months in quarter T, plus, in fact, the first month in quarter $(T + 1)$. Specifically, we consider the Economic Sentiment Indicator (ESI).[2] The ESI, published by the European Commission, is a widely used composite indicator. The ESI combines various information from qualitative business tendency surveys, including expectations questions, into a single cyclical confidence indicator. We do not consider indicator variables like interest rates since, whatever their influence on demand, we believe that they are not so suitable for the production of (pre-) first estimates of data (as opposed to forecasts), since they do not have such clear links to the data they are supposed to represent.

This means that the nowcasts of GDP growth are constructed from three-variable quarterly VAR models (i.e. $k = 3$ and $\mathbf{x}_{it}$ is a 3×1 vector and comprises GDP growth, IP growth, and the survey data). As mentioned, in fact, six-variable unconditional VARs in $\mathbf{x}_{it}$ and their foreign counterparts $\mathbf{x}^*_{it}$ are estimated to accommodate the endogeneity of these foreign variables. There is a question about whether the survey data should be considered in levels or first differences. Results below are based on first differences, but are little affected by the transformation. We focus in the application below on first-order VAR models; as described above, when nowcasting, we have a preference for parsimonious dynamics. But, in any case, consideration of higher-order VARs did not deliver more accurate nowcasts in this application.

[2] ESI data are not available for Ireland. Instead, we use DG-ECFIN's Consumer Confidence Indicator up to April 2008; thereafter the Consumer Sentiment Index, as published by the Economic and Social Research Institute in Ireland.

9.4.2 *Real-time simulation exercise*

We compare the accuracy of these nowcasts of euro-area GDP growth 30 days after the end of the quarter, in recursive out-of-sample experiments using real-time data. Specifically, we use the real-time data triangles for real GDP and industrial production available from Eurostat's real-time EuroIND database for the EA(12) aggregates as well as the 12 countries.[3] The qualitative survey data are not revised (in a significant manner at least). Models are estimated on data vintages back to 2001 with data back to 1991q1. Seasonally adjusted data are used.

It is important to use real-time data, namely data available to the forecaster at the time they actually made their forecast, rather than the latest release from Eurostat, given that data are revised. Use of the latest vintage of data may give a misleading impression of the accuracy of a given forecasting model/strategy, since in reality the forecaster used an earlier vintage of the data to make their forecasts. We therefore use the latest vintage of data available to the forecaster when they made their forecast.

The nowcasts are evaluated by defining the 'outturn' as both the first (Flash) GDP growth estimate from Eurostat and the latest or 'final' (as of February 2011) vintage, which contains GDP data up to 2010q4. The exercise could be repeated for different definitions of the outturn, say the second or third release. But as our primary interest is in accelerating delivery of national accounts data, the first estimate does appear to be the obvious benchmark.

9.4.3 *Nowcasting results*

Nowcasts for GDP growth are computed recursively from 2003q2–2010q4 using the direct, indirect and GVAR models. Evaluation starts in 2003q2, as this is when Eurostat first published its own Flash estimate.

Table 9.1 summarizes the accuracy of the different nowcasts by reporting their RMSE statistics against both the first (Flash) estimate and the latest (or 'final') estimate. As a benchmark we consider a random walk forecast. All three nowcasting approaches deliver more accurate estimates than this benchmark forecast; reassuringly, conditioning on within-quarter information improves accuracy. Table 9.1 also shows that the proposed GVAR nowcasts are more competitive than the commonly used direct approach to

[3] The aggregated real GDP data for the EA12 is computed as the sum (in millions of euros) of the disaggregate GDP series of the 12 individual countries. These data are virtually indistinguishable from aggregate (EA12) GDP data, which can be downloaded directly from Eurostat.

nowcasting an aggregate. But the GVAR's nowcasts are less accurate than those from the indirect approach, itself a restricted GVAR.[4]

To give an impression of their changing performance over time, Figure 9.1 plots the competing nowcasts against Eurostat's first (Flash) estimate, over the evaluation period. This figure shows that, in fact, the GVAR picked up the severity of the descent into recession in 2008 better than the other nowcasting approaches.[5] Of the nowcasting methods, the direct approach, in particular, detected the downturn only at a lag. But the GVAR did overestimate both the depth of the recession and the magnitude of the subsequent bounceback; the GVAR nowcasts appear more volatile than their competitors.

Experimentation with estimation of the GVAR over different estimation windows indicated considerable parameter estimation uncertainty (see Lui and Mitchell, 2012 for details); and this translated into RMSE estimates both considerably worse and better than those reported in Table 9.1 when the GVAR was estimated only using a (recursive, expanding) data window spanning back to 1991q2. This motivates Lui and Mitchell (2012), following

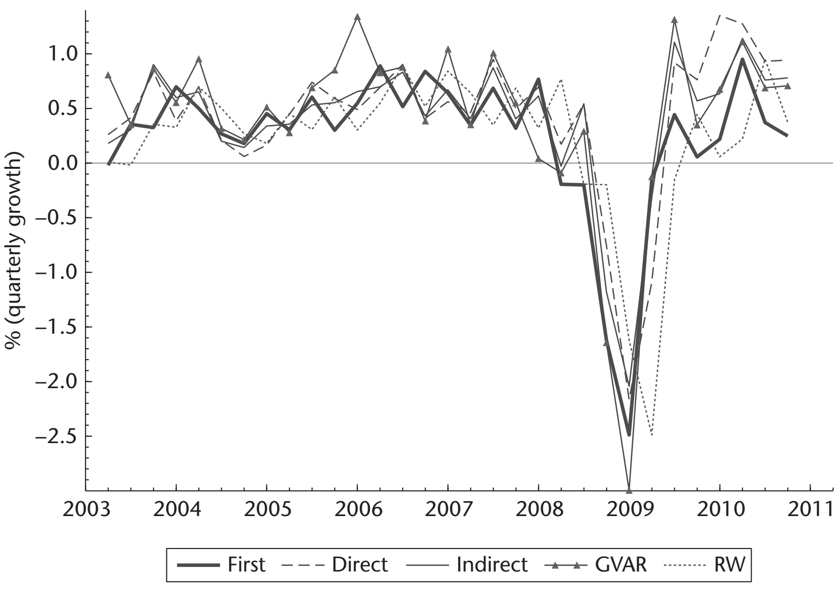

Figure 9.1. Competing nowcasts at $t + 30$ days of Eurostat's first (Flash) GDP growth estimate published at 45 days.

[4] We eschew the use of Diebold-Mariano type tests to test the statistical significance of these forecast accuracy differences, given our relatively short evaluation period.

[5] See Lui and Mitchell (2012) for details on how and why this temporal change in relative performance occurred.

Table 9.1. RMSE of competing nowcasts of EA GDP growth (quarterly growth rates), 2003q2–2010q4.

	First	'Final'
Direct	0.46	0.49
Indirect	0.32	0.37
GVAR	0.41	0.41
Random walk	0.63	0.67

Note: The nowcasts are evaluated against both the First (Flash) GDP growth estimate from Eurostat and the 'Final' (February 2011) vintage.

Pesaran et al. (2009), to consider the combination of nowcasts from GVAR models, estimated over a range of different estimation windows, as a means of delivering more robust nowcasts.

To indicate the benefits of conditioning the GVAR nowcasts (of the aggregate) on country-level GDP data, when available for quarter t, we note that if we conditioned only on Belgian GDP (and not Spanish GDP as in Table 9.1) then the RMSE statistics rise to 0.48 and 0.49, respectively. In turn, if the German GDP were published at 30, rather than 45, days after the end of the quarter, and we conditioned on them in the GVAR, the RMSE statistics for the GVAR in Table 9.1 would fall to 0.25 and 0.28, respectively.

9.5 Conclusions

We show that the global VAR model of Pesaran et al. (2004) offers a theoretically attractive means of computing nowcasts of aggregates, like euro-area GDP growth. Since publication lags for data vary both by country and by indicator variable, it is important to use a multivariate model that accommodates both cross-country and cross-variable dependencies when nowcasting. Then the nowcast can be conditioned on all available disaggregate information. The GVAR provides a computationally convenient means of estimating this multivariate model and, in theory, delivers minimum RMSE nowcasting errors.

In an illustrative application, using real-time data, nowcasts for euro-area GDP growth are produced 30 days after the end of the quarter. This is 15 days earlier than Eurostat's own Flash estimate, and in line with when both *advance* US GDP and *preliminary* UK GDP data are first published. We find that the proposed GVAR nowcasts are more competitive than the commonly used direct approach to nowcasting an aggregate. But parameter estimation error means that, in practice, the GVAR's nowcasts are less accurate than those from the indirect approach, which itself is simply a restricted GVAR. This finding is consistent with Lütkepohl (1984) and Giacomini and Granger (2004); parameter estimation error reduces the accuracy of the GVAR's (or multivariate model's) nowcasts. But, as Lui and Mitchell (2012) consider in detail, the GVAR nowcasts are more competitive, specifically over the 2008-9 recession, than both direct and indirect approaches.

That there is considerable parameter estimation uncertainty is not surprising in this application, which is characterized by not just a small T sample, but by 'structural instabilities' reflecting the sharp recession in the aftermath of the global financial crisis beginning in 2007. In Lui and Mitchell (2012) we consider how combination, over different estimation windows, can yield more robust GVAR nowcasts. In a forecasting application, Pesaran et al. (2009) also found that combination of the GVAR helps. Other ongoing developments involve consideration of a mixed-frequency rather than quarterly (bridge) GVAR, as considered here. However, in Lui and Mitchell (2012) we did find only marginal improvements in nowcast accuracy at the country-level when mixed-frequency VAR rather than quarterly (bridge) VAR models were used. Consideration of a wider range of indicators, possibly in conjunction with a factor model or using the mixed-approach of Hendry and Hubrich (2011), is another possible means of further improving nowcast accuracy.

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Part II

Finance applications

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10

Macroprudential applications of the GVAR

*Alexander Al-Haschimi and Stéphane Dées**

10.1 Introduction

The unexpected severity of the financial crisis has triggered a broad-based review of the conduct of financial supervision. In retrospect, the macroprudential dimension of financial supervision required better tools to anticipate the build-up of financial imbalances and to understand how their unwinding can impact the real economy. To this end, macroprudential supervision aims at identifying and containing risk at the level of the financial system at large.[1] This is generally referred to as systemic risk, which can be defined as the risk that financial instability increases to the point where the functioning of the financial system is impaired and has material adverse effects on the real economy (ECB, 2009).

One central challenge for the monitoring of systemic risk is its measurement. For effective financial supervision, it is essential to have tools that can measure the probability and quantify the impact of future episodes of financial instability. This is a challenging task because periods of financial distress are infrequent, and a system can be unstable for a sustained length of time without giving rise to financial stress (Borio and Drehmann, 2009). As such, tools that can provide a counterfactual assessment of the systemic reaction to a given shock are an important component in the toolbox for macroprudential supervisors. This chapter discusses how the GVAR can be effectively employed for this purpose.

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[1] See, e.g. Galati and Moessner (2011) for a literature review on macroprudential policy.

10.2 Macro stress-testing models

Macro stress-testing models typically measure the impact of an exceptional but plausible adverse macroeconomic shock on individual financial firms or groups of firms. The dependent variable may represent firm- or industry-specific default probabilities, loan loss provision measures, probabilities of rating changes, or other indicators of firm-level distress. Linked to these indicators is a macroeconomic model that is used to generate a set of adverse shocks. These macroeconomic shocks represent tail risks that are either explicitly modelled with a probability distribution, or are designed through a particular scenario that can also draw on sources of risk that are external to the model at hand.

Previous work on the links between macroeconomic variables and indicators of corporate stress includes Alves (2005) and Shahnazarian and Asberg-Sommer (2009). In these analyses, Moody's KMV expected probabilities of default (EDF) are incorporated in co-integrated VAR models in order to analyse the responses of corporate sector EDFs to macroeconomic shocks. Alternatively, macro engines can take the form of structural econometric models, and even purely statistical methods, such as in Boss et al. (2006), who employ a number of statistical techniques including *t*-copula functions to derive a multivariate distribution that is estimated based on historical changes in market prices and relevant macroeconomic variables.

While research on macro stress-testing models has increased substantially over recent years, current empirical methods remain subject to a number of substantial shortcomings.[2] For instance, many stress-testing models are limited to domestic macroeconomic variables, while the recent crisis has shown that international linkages provide key avenues for the transmission of financial shocks. Another shortcoming is the largely (log) linear setup of most stress-testing models, whereas confidence effects and sudden changes in risk aversion may give rise to nonlinear reactions to large shocks. Feedback effects from the financial sector to the real economy are also often neglected. However, it was precisely this spillover that translated the recent financial crisis into the great recession. Finally, model parsimony often comes at the expense of adequately accounting for heterogeneity among firms as well as the interconnectedness between the financial and non-financial sectors.

In what follows, we will illustrate how the GVAR has been applied as a stress testing tool, and how the GVAR framework can be used to overcome

[2] For recent reviews of macro stress testing models, see Alfaro and Drehmann (2009), Drehmann (2009), and Foglia (2009).

the methodological shortcomings mentioned above. While we will focus on applications that relate macroeconomic variables to measures of default probabilities, other indicators of firm-level distress can be used instead.

10.3 Probability of default as a measure of credit risks

In the empirical literature, there are many ways to measure firm-level distress. Due to the lack of harmonized bankruptcy data, many empirical studies opt for measures of firm-specific probabilities of default. For instance, Moody's KMV expected default frequency (EDF) measures the probability that a firm defaults within a given time horizon. A firm with an EDF of 1% would have a 1% probability of defaulting within the next 12 months. The EDFs are based on the contingent claim approach to measure probability of default (see Merton, 1974). More precisely, a firm is considered in default when the market value of its assets is less than its debt. Vassalou and Xing (2004) call this measure of risk the equity market-implied default risk, where the probability of default is a function of the current value and volatility of its assets relative to the expected future payments on its debt. The Merton model provides a framework to estimate the implied asset value and volatility using equity market data and balance sheet information.

Other default probability models have been developed. For instance, Kamakura (2011) provides default probability measures based on multiple modelling approaches. In addition to default probabilities that are derived from a Merton-type structural model, Kamakura also uses a statistical hazard model (see Chava and Jarrow, 2004), which relates a firm's default probability to explanatory variables that include firm- and industry-specific variables, as well as macroeconomic factors based on an empirical evaluation of the variable's predictive content. While by some measures the empirical Jarrow–Chava model may be a more accurate indicator of default risk than the theory-driven Merton approach, the explicit dependence of the Jarrow–Chava-based default risk measures on macroeconomic factors would give rise to problems of endogeneity when regressed on macroeconomic variables.

10.4 Applications of the GVAR to macro stress testing

By providing a framework that accounts for both real and financial channels, the GVAR modelling approach is particularly suitable for analysis of the transmission of real and financial shocks across countries and regions.

Indeed, GVAR-based stress tests are being used at a number of central banks; see, e.g. Alessandri et al. (2009) and Castren et al. (2009).

Here, we will focus on two applications of the GVAR model that link probability of default data with macroeconomic variables. First, Castren et al. (2010) connect a GVAR model with measures of euro-area corporate sector credit quality by constructing a satellite model linking the probability of default to a set of macroeconomic and financial variables. This 'satellite-GVAR model' is used to analyse the impact of dynamic macroeconomic stress-test scenarios on probabilities of default. The second application, by Chen et al. (2010), distinguishes between banks' and non-financial corporates' default risks and includes EDF data as endogenous variables in the country-specific models of the GVAR. This approach therefore allows for two-way relationships between the macroeconomic and the corporate distress variables as well as spillover between the financial and non-financial corporates.

10.4.1 *The satellite-GVAR approach*

Castren et al. (2010) use the GVAR to estimate the impacts of domestic and global macroeconomic shocks on the default probabilities of euro-area firms measured with the Moody's KMV EDF data. The approach followed consists of adding satellite equations modelling EDFs to the GVAR model developed in Dées et al. (2007), and described in Chapter 2 of this book. Although this framework ignores the feedback effects from the EDFs to the macroeconomic variables, it helps connect two different modelling approaches without affecting the structure and the properties of the GVAR model, which has been tested and used for other purposes.

The simplest form of the satellite model estimated by Castren et al. (2010) is given by:

$$\mathrm{EDF}_{jt} = \alpha + \beta_1 \Delta\mathrm{GDP}_t + \beta_2 \Delta\mathrm{CPI}_t + \beta_3 \Delta\mathrm{EQ}_t + \beta_4 \Delta\mathrm{EP}_t + \beta_5 \Delta\mathrm{IR}_t + \varepsilon_{jt}, \quad (10.1)$$

where j is the index for sectors, α and β are the parameters for sector-j equation, $\Delta\mathrm{GDP}_t$, $\Delta\mathrm{CPI}_t$, $\Delta\mathrm{EQ}_t$, $\Delta\mathrm{EP}_t$, and $\Delta\mathrm{IR}_t$ denote the logarithmic difference of euro area GDP, CPI, real equity prices, real euro/US dollar exchange rate, and short-term interest rate at time t, respectively, and ε_{jt} is the vector of residuals. The endogenous variables of the GVAR are treated as exogenous in the satellite model, which in turn has no feedback on the GVAR.

The satellite-GVAR structure allows us to handle the fact that the satellite model includes EDF data that cover a shorter period than for the macroeconomic and financial series of the GVAR model. Although the lack of feedback between the satellite and the GVAR could be seen as problematic, the inclusion of financial variables (such as equity prices) in the macroeconomic model partly captures the impacts of macroeconomic shocks on the corporate sector.

The EDF data for euro-area firms are grouped by economic sectors, using seven broad industries: basic goods and construction (BaC), energy and utilities (EnU), capital goods (Cap), consumer cyclical (CCy), consumer non-cyclical (CNC), financials (Fin), and technology, media, and telecommunications (TMT). As a benchmark, Castren et al. (2010) also consider the aggregate EDF (Aggr) across the entire data set. Once the industrial sectors have been defined, there is a number of ways to aggregate the firm-level EDF information into measures of sectoral probabilities of default. The simplest solution (chosen here) is to take the sector's sample median where the median EDF at each point in time represent the median EDF among a panel of available corporations in a sector. Alternatively, Castren et al. (2010) also use the median-leverage in each sector, in order to choose a representative firm in the euro area and in each sector.

Table 10.1 presents the estimated satellite model for sector-median EDFs. The results show that most of the parameters are significant, except in a few cases, and their signs are similar across the sector-median EDFs. In particular, the estimation shows that a decrease in GDP growth leads to an increase in the expected probability of default in all sectors in the euro area. The effect is particularly strong for the Bac, Cap, and CCy sectors that are more sensitive to cyclical conditions. A decrease in equity prices also implies an increase in the EDF owing to a tightening in the overall financing conditions. An appreciation of the euro exchange rate vis-à-vis the US dollar increases the expected probability of default, which might reflect the relatively strong trade openness of the euro area. The impact of inflation is less clear-cut and varies across sectors. The financial sector (Fin) seems to be the most sensitive to inflation, while it is not significantly affected by changes in

Table 10.1. Results of the satellite-GVAR regressions for the sector median EDFs (1992q1–2005q4).

EDF regression/parameters	ΔGDP_t	ΔCPI_t	ΔEQ_t	ΔEP_t	ΔIR_t	R^2
Aggr	−0.350**	−0.054	−0.018**	−0.028*	−0.010	0.377
Bac	−0.285**	0.161	−0.014**	−0.012	−0.007	0.470
Cap	−0.465**	−0.097	−0.022**	−0.034*	−0.011	0.371
CCy	−0.266**	0.018	−0.015**	−0.017	−0.006	0.417
CNC	−0.117	−0.100	−0.010**	−0.012	−0.003	0.267
EnU	−0.047*	0.031	−0.005**	−0.002	0.000	0.406
Fin	−0.030	0.081**	−0.003**	−0.002	−0.001	0.469
TMT	−1.179*	−0.831	−0.062*	−0.135*	−0.038	0.328

real GDP growth. Finally, the coefficients of short-term interest rates are not significant in most cases.

The satellite model, once estimated, is integrated into the GVAR model developed by Dées et al. (2007). This extension of the DdPS model (see Chapter 2) imposes long-term restrictions on the co-integrating vectors in line with economic theory. The satellite model is integrated into the GVAR by adding the EDF equations to those of the GVAR and linking the exogenous EDF series to the GVAR variables shown in equation (10.1). For instance, the GVAR model includes euro-area real GDP or equity prices as endogenous variables, which are also present as exogenous in the satellite model. Stacking the two models together provides a single framework that inputs the GVAR-based impulse responses of these variables to the satellite equations. This is used to compute impulse responses of the EDFs following various macroeconomic shocks. Overall, most sector-median EDFs react similarly to the benchmark aggregate case.

Starting with shocks to activity, we see first that a negative one-standard-deviation shock to the euro-area real GDP increases the median EDFs of the different sectors (Figure 10.1). The financial sector is the least affected compared to the other sectors, while the reaction in the IT sector (TMT) is much larger than the aggregate benchmark. As seen earlier, the financial sector is relatively insensitive to real shocks, while for this shock, as well as for the subsequent ones, the EDFs of the TMT sector react systematically more than for the other sectors. This is likely to be related to the sample used in this application (1992–2005), which was dominated by the dotcom boom and bust in the early 2000s. By contrast, the financial sector was relatively unaffected by economic developments. An update of this exercise, taking into account the most recent financial crisis, would certainly change such results.

The GVAR model allows us to also compute the effects of global shocks (see Chapter 2). Figure 10.2 shows the impacts of a global GDP shock on euro-area EDFs. The effects are slightly stronger in the short term relative to the responses to a shock to euro-area GDP. This suggests that the expected default of euro-area firms could be more sensitive to disturbances in the global economy than in the domestic economy, at least in the short term. Moreover, as expected, the median EDF of the cyclical sectors tends to react initially more strongly than the non-cyclical-sector EDFs to business cycle conditions.

The second set of shocks is related to financial variables. A negative shock to real equity prices has relatively large impacts on EDFs. In the short term, responses of EDFs are stronger following global rather than euro-area equity shocks (Figures 10.3 and 10.4). The long-term impact responses, however, are comparable.

Finally, the appreciation of the euro against the US dollar increases the median EDFs, indicating that the loss in export price competitiveness appears to overcompensate other positive impacts (e.g. lower imported input prices), thus raising the expected default of euro-area firms (Figure 10.5).

Overall, the results show that the median EDFs of euro-area firms react to macroeconomic and financial shocks (GDP, equity prices, and exchange rates) and that there are limited cross-sector differences in the profile of the responses. However, the magnitudes of the responses are rather diverse across sectors. For instance, the technology sector (TMT) shows the largest reactions to shocks, while the financial sector (Fin) is in most cases the least affected. More generally, the cyclical sector median EDFs tend to react more to business cycle variables than the non-cyclical sector EDF.

10.4.2 *Endogenizing firm-level distress measures in the GVAR*

Chen et al. (2010) also provide a framework linking EDF data and macroeconomic variables based on the GVAR modelling approach. However, contrary

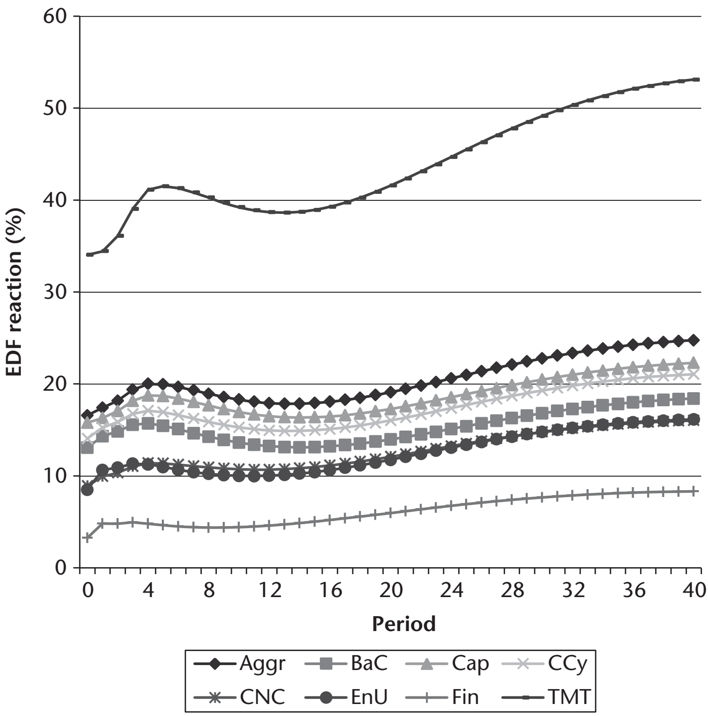

Figure 10.1. Euro area—negative GDP shock.

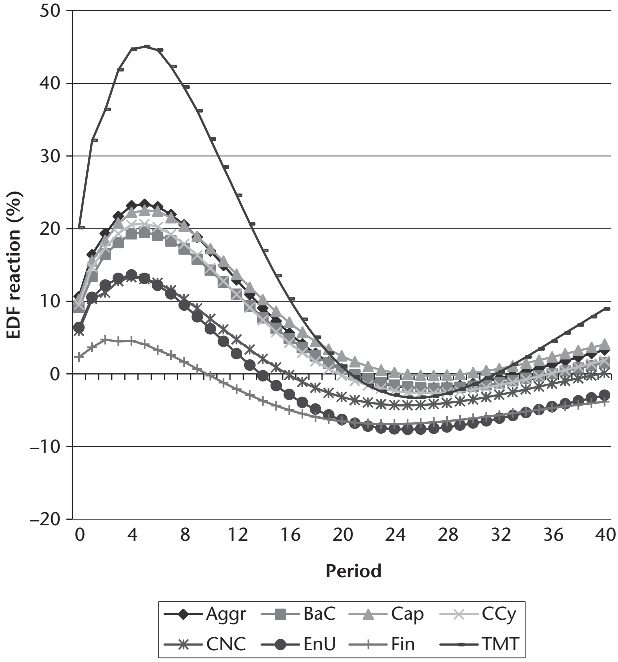

Figure 10.2. Global—negative GDP shock.

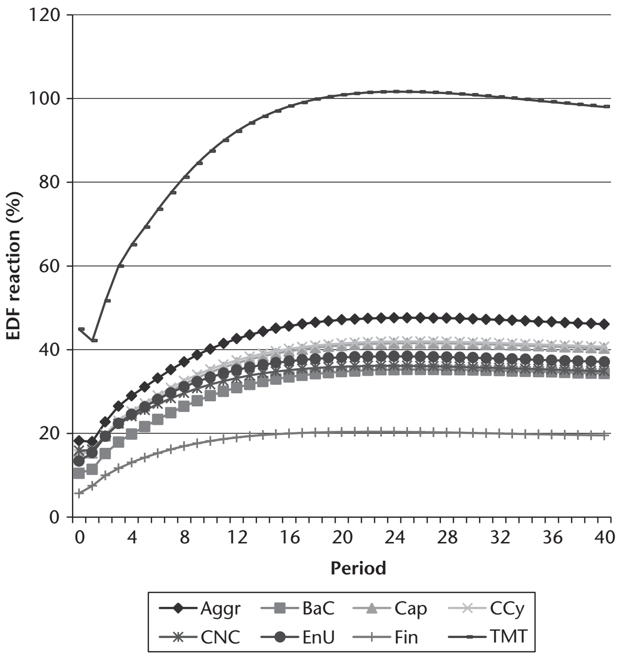

Figure 10.3. Euro area—negative equity price shock.

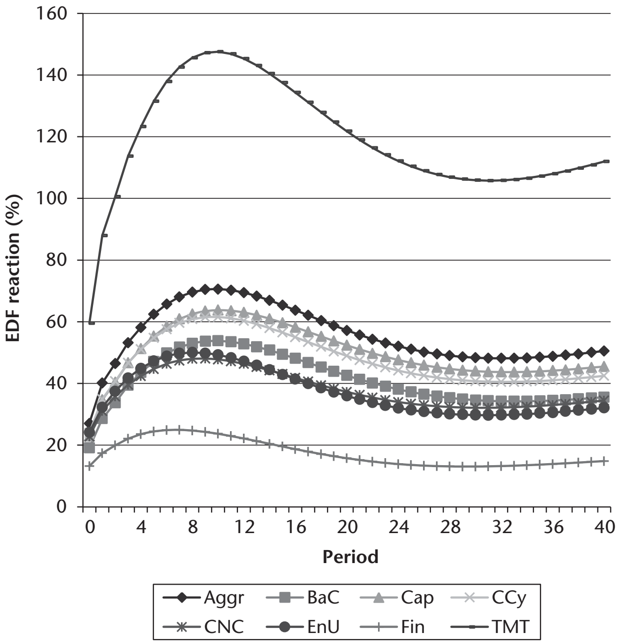

Figure 10.4. Global—negative equity price shock.

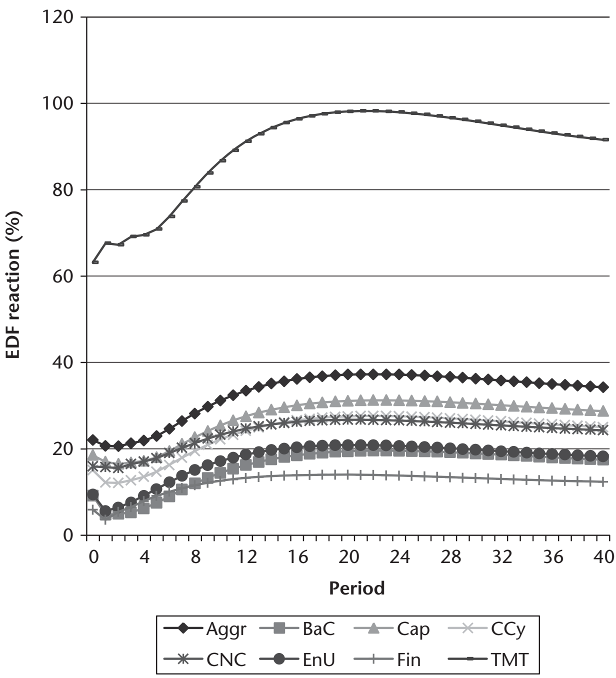

Figure 10.5. Euro area—negative exchange rate shock (i.e. appreciation).

to Castren et al. (2010), the corporate default data are included among the endogenous variables. As a result, the model is able to capture the two-way relationship between the macroeconomic variables and the firm data. The GVAR model used in this application includes industrial production, short-term interest rates, real effective exchange rates, and stock prices as macro-economic variables. The price of oil is also included as a common observed factor. The EDF data, separated between banks and non-financial corporates, enter the model as endogenous variables.

All variables but real effective exchange rates have a foreign counterpart in the country-specific VARX* model. For the US model, however, only foreign output enters the vector of foreign variables, given the important role of the US in the financial markets.

Like in any GVAR modelling exercise including N countries, the country-specific foreign variables are constructed as a weighted average of the corresponding variables of the $N-1$ other countries included in the model. For financial variables (EDFs, interest rates, and equity prices), Chen et al. (2010) use financial weights derived from the currency exposure measures of Lane and Shambaugh (2010), which summarize bilateral financial asset positions on five different types of instruments (equity, debt, direct investment, other bank-related debt, and reserves). For measuring foreign industrial production, they use trade weights based on bilateral trade in goods data as reported in the IMF Direction of Trade Statistics.

The GVAR used includes 21 advanced economies and 19 emerging economies. The data are of monthly frequency over the period 1996–2008. Country-specific EDF data are computed as asset-weighted averages of 12-month-ahead EDFs for banks and non-financial corporates.

To identify shocks to EDFs, Chen et al. (2010) use a Cholesky decomposition assuming a Wold ordering of output, interest rates, equity prices, real effective exchange rates, non-financial EDFs, and bank EDFs for the US model. Ordering output as the first variables implies that activity does not react contemporaneously to the financial shocks. Bank EDFs are assumed to react contemporaneously to non-financial corporate EDFs and not the other way around given the role of banks in financing the corporate sector.

Overall, the analysis shows that the increase in EDFs of corporates in a country has negative impacts on that country's activity, confirming the importance of accounting for spillovers between the corporate sector and the macroeconomy. It is also shown that bank distress amplifies corporate distress and has in turn negative macroeconomic implications. Concerning the international linkages, the empirical analysis shows that the cross-country spillovers are stronger when the shock originates in large, advanced economies, and in the US in particular. Advanced economies tend to be more vulnerable to shocks to banks than shocks to non-financial corporates. This results from the role played by the financial sector in these countries. By contrast, the transmission of shocks to EDFs originating from advanced economies to emerging economies tends to be larger when it affects corporates than when it affects banks. This confirms that trade channels are relatively stronger than financial channels in the transmission of shocks from advanced economies to emerging economies.

10.5 Accounting for firm-level heterogeneity: avenues for future research

In the GVAR applications examined in Section 10.4, firm-level distress is measured at country or industry level, using median or asset-weighted measures of expected default. However, these aggregate measures cannot account for potentially sizeable heterogeneity across firms. For example, among a set of euro-area industrial companies, sample correlations between the EDFs and euro-area equity prices over the period 1992q1–2009q4 range from −0.08 to −0.55, with different implications for the sensitivity of a particular firm to a given macroeconomic shock.[3] Moreover, aggregate measures such as the median can hide underlying distress in one or more firms that are possibly systemically important. Finally, some individual firms, such as large banks, may be highly exposed to a relatively small set of other large banks, which is not taken into account in aggregate measures. While Chen et al. (2010) use asset-based weights to aggregate firms, this may downplay the significance of smaller, yet highly connected, financial companies.[4]

One challenge that arises from incorporating firm-level distress indicators endogenously in a VAR framework is of course the curse of dimensionality, given a potentially large set of firm-level variables and the typically limited availability of historical data. However, recent methodological advances in high-dimensional VARs in principle allows the combination of a large macroeconomic model such as a GVAR with a potentially large and endogenous set of firm-level data.

[3] Based on data from Kamakura.

[4] For additional discussions about the effects of aggregating micro units, see, e.g., Pesaran and Chudik (2012) and Gabaix (2011).

Specifically, the infinite-dimensional VAR (IVAR) framework developed by Chudik and Pesaran (2011, 2012) introduces a novel approach for estimating VARs, where the number of variables N and the number of observations T are both large. Specifically, consider an N-dimensional vector x_t that follows a VAR(1) process, such that

$$x_t = \Phi x_{t-1} + u_t \tag{10.2}$$

where

$$u_t = R\varepsilon_t$$

and where Φ and R are $N \times N$ parameter matrices that represent the dynamic and contemporaneous relationships among the variables in x_t, which we can consider to be firm-level EDFs in this context and ε_t is a $N \times 1$ vector of white noise disturbances. As there are N^2 parameters in Φ, the model in (10.2) cannot be estimated directly when N is large. Instead, Chudik and Pesaran (2011) assume that for a given unit in x_t, the remaining firms can be divided into a relatively small set of so-called 'neighbours', while the other firms are classified as 'non-neighbours'. Essentially, while there are no restrictions on the neighbours, the coefficients of the non-neighbours are assumed to tend to zero for each firm i as $N \to \infty$. In the aggregate, however, the set of non-neighbours may have non-negligible effects on firm i. This may arise in the presence of strong cross-section dependence that could result, for example, from an unobserved factor common to all firms. Under a given set of conditions detailed in Chudik and Pesaran (2011), the parameters of the IVAR in (10.2) can be consistently estimated using firm-by-firm cross-section augmented regressions, where x_{it} is regressed on its own lags, its neighbours' x_{jt}, and where the individual non-neighbours are replaced by cross-section averages. This approach greatly reduces the number of parameters to be estimated, while, similarly to the GVAR framework, the system in (10.2) can be recovered from the firm-level estimates.

The IVAR approach can be readily applied to a macro stress-testing framework. Given a set of EDFs for a country's financial and non-financial firms, one can *ex ante* determine the existence of neighbours, if any, by e.g. considering bilateral exposures or by using other measures of market structure.[5] This IVAR can be augmented with a set of domestic macroeconomic variables, which would enter each firm's equation. As such, these macroeconomic variables act as so-called 'dominant units' or observed common factors. Pesaran and Chudik (2012) show that in the presence of both

[5] See, e.g. Jorion and Zhang (2009) for an approach to identify firm-level counterparty risk among industrial and financial firms.

observed and unobserved common factors, the impact of the dominant unit(s)—represented by macroeconomic variables in the context of stress-testing models—can be consistently estimated with firm-level regressions that are augmented with distributed lag functions of the cross-section averages and the dominant units, or macroeconomic variables.

The resulting stress-testing model is very flexible. Most importantly, it links a potentially large set of firms *individually* to macroeconomic shocks, thereby accounting for the observed heterogeneity among firm-level measures of distress. In addition, the model framework allows for detailed specifications of spillover effects of firm-level distress among a limited set of firms, or neighbours. Direct spillover effects can also be assessed between subsets of firms, such as the interaction between the financial and non-financial sectors. By specifying a law of motion for the domestic macroeconomic variables that also includes cross-section averages of the firms, two-way feedback between the firms and the macroeconomy can be modelled. And finally, by adding a GVAR block to introduce non-domestic macroeconomic variables, one can also explicitly account for the international transmission of economic and financial shocks. Overall, the infinite-dimensional VAR framework holds the potential to add firm-level granularity to the stress-testing model domain that has thus far been a major constraint of the current generation of models.

10.6 Concluding remarks

The GVAR has proven to be a useful tool for macroprudential supervision and is already applied to macro stress testing exercises at a number of institutions. For instance, Castren et al. (2009) link a GVAR model to a credit portfolio model to simulate changes in banks' credit losses resulting from an increase in the default probabilities of their borrowers. Such macro stress testing frameworks are therefore useful for risk management processes, as well as for the financial stability analyses that are developed in central banks and by supervisory authorities.

Macroprudential applications of the GVAR continue to evolve. Chen et al. (2010) have shown how to endogenize corporate distress and account for spillover effects between the financial and non-financial sectors. Further developments in the GVAR methodology, and in particular the adaptation of infinite-dimensional VARs to introduce systems of individual firms, provide promising avenues for further research that aim to capture the complex interactions between heterogeneous economic actors.

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11

Modelling sovereign bond spreads in the euro area: a nonlinear global VAR model

*Carlo A. Favero**

11.1 Introduction

Mapping macroeconomic and fiscal dynamics into sovereign spreads in the euro area is a very important task for policy analysis but also a daunting one. In fact, the nature of co-movements among bond spreads is very different from that of real variables. Figures 11.1 and 11.2 provide some graphical evidence on this issue. Figure 11.1 reports fluctuations of log real per capita demeaned GDP[1] of 11 euro-area countries and of the spreads of 10-year government bonds on German bunds with the same maturity. The figure illustrates that instability in the co-movements among spreads is much stronger than that in the co-movements of real variables. Figure 11.2 illustrates the heterogeneity in co-movements of real and financial variables in the Euro area by reporting the time series of cross-sectional means and standard deviations of log per capita GDP differentials between euro-area countries and Germany and spreads on German bunds for the same countries. The cross-sectional first and second moments of GDP differentials are rather stable over time, while the cross-sectional moments of the spreads on bund are much more volatile.

This feature of the data provides a very serious challenge for modelling the common trend between financial spreads and for mapping slowly evolving

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[1] Demeaning here is to be taken as a simple rescaling device for graphical purposes. The presence of a unit-root in the log of GDP would prevent the definiton of the unconditional mean.

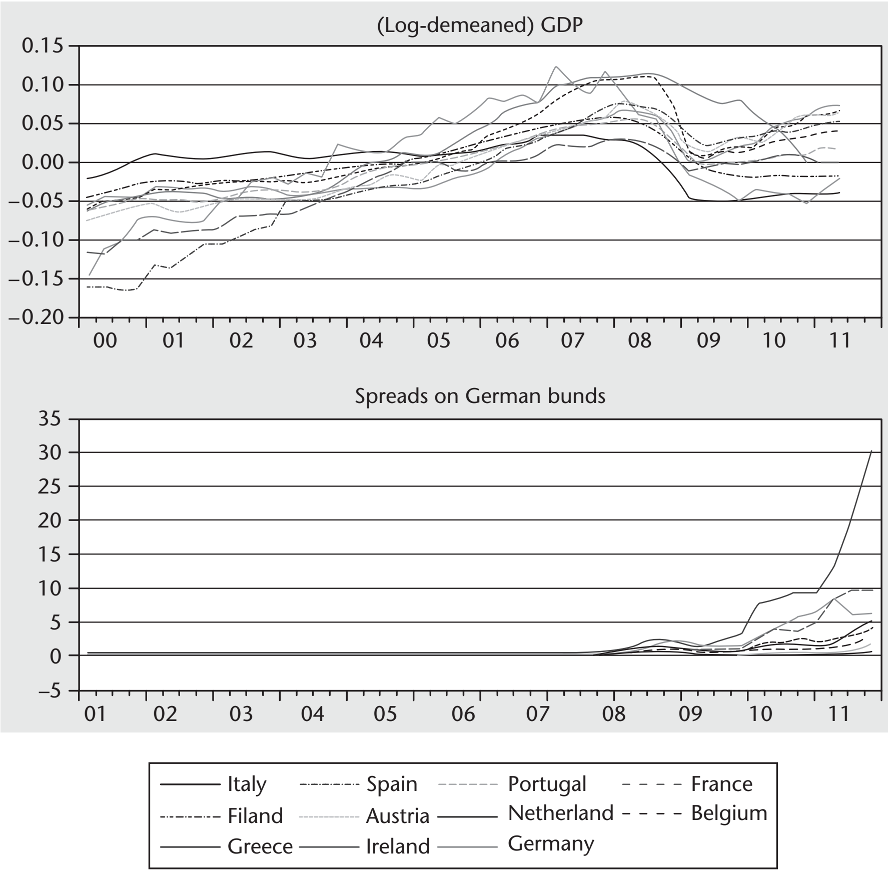

Figure 11.1. Co-movement of real and financial euro variables.

and persistent macroeconomic fundamentals into the volatile time-series behaviour of spreads. Traditionally, the GVAR approach has been used to identify common and idiosyncratic trends in macroeconomic fundamentals that are then linearly mapped into returns on a portfolio of credit assets to conduct policy analysis on the effect of changes in macroeconomic risk factors into credit risk (see, for example, Pesaran, Schuermann, and Weiner 2004; Pesaran and Smith 2006; Pesaran, Schuerman, Treutler, and Wiener 2006). As the linear mapping between macroecomic factors and returns cannot accommodate the different nature of co-movements between bond spreads and economic fundamentals, we propose to model this heterogeneity in a nonlinear global VAR model of the spreads on bunds. In this specification the dynamics of each spread on German bund is determined by a local variable, i.e. countries, fundamentals relative to the German ones,

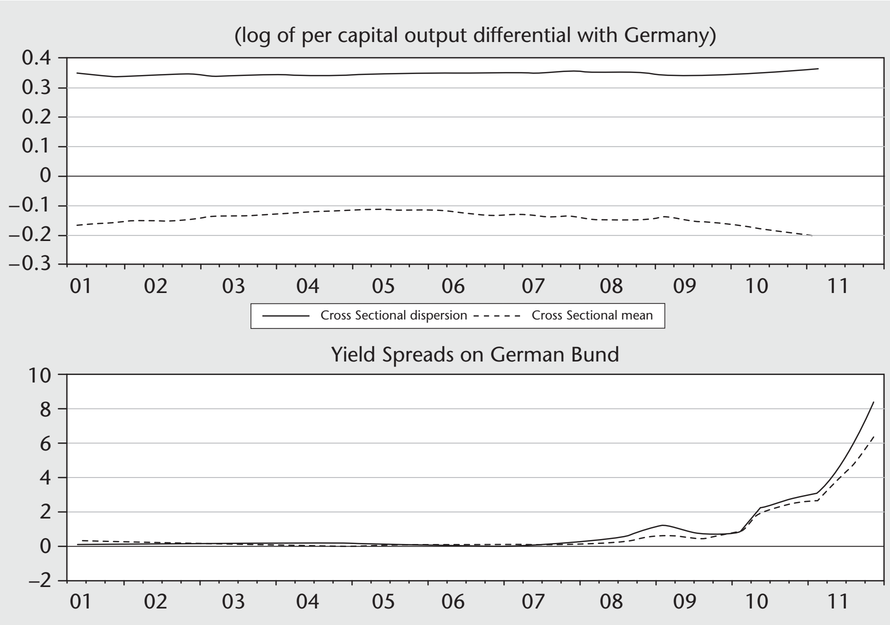

Figure 11.2. Cross-sectional means and standard deviations of euro-area output diffrentials with Germany and 10-year bond spreads on bund.

a global European variable that models the exposure of each country's spread to the other spreads in the euro area in terms of the 'distance' between their fiscal fundamentals and a global non-European variable, the US Baa-Aaa spread. The global European variable for each country's spreads on Germany is determined by a weighted average of spreads in all other countries in which the weights are constructed to make the factor more dependent on the spreads of those countries that are more similar in terms of fiscal fundamentals. This framework modifies the traditional GVAR approach where global macrovariables are constructed for each country by using trade weights. Using the distance in terms of fiscal fundamentals makes the global variable country-specific, as in the traditional GVAR framework, but the weights more volatile than in standard GVAR based on trade weights. The changing weights, related to the changing expectations for fiscal fundamentals, have the potential of explaining the changing correlation among spreads. This specification explicitly allows for a nonlinear relationship between spreads and fiscal fundamentals. Fiscal fundamentals are important in the determination of the spreads as they define the distance between countries and therefore select the reference group relevant to determine the global variable that influences different spreads. This framework allows for an important degree of flexibility in modelling the interdependence among long-term interest rates in euro-area countries.

This model rationalizes the time-varying nature of the co-movements between bond spreads in the euro area, mainly driven by credit risk (Codogno et al., 2003; Geyer et al., 2004; Bernoth et al., 2006; Aßmann and Boysen-Hogrefe, 2009; Beber, Brandt, and Kavajecz et al., 2009; Haugh et al., 2009; Manganelli and Wolswijk, 2009; Sgherri and Zoli, 2009; Attinasi et al., 2010; Schuknecht et al., 2010; Laubach 2009, 2011).

The specification of the model is introduced in the next section. We then discuss and illustrate the potential of the model by implementing impulse response analysis, out-of-sample forecasting and simulation analysis. Finally, we show how the GVAR can be used to address the issue of financial contagion among euro-area spreads and the relative role of fundamentals and market sentiments in their determination.

11.2 A nonlinear GVAR model for 10-year bond differentials in the euro area

Long-term yield differentials in the euro area co-move but with an unstable pattern of co-movements over time: yields converged significantly with the introduction of the euro, narrowing from highs in excess of 300 basis points in the pre-EMU period to less than 30 basis points about one year after the introduction of the euro. Yet, bonds issued by euro-area member states have never been regarded as perfect substitutes by market participants: interest rate differentials co-moved synchronously at a very low level between the introduction of the EMU and the subprime lending crisis, and they became sizeable during the course of 2008 and 2009, with some separation in co-movements between high-debt and low-debt countries. The euro debt crisis brought about differentials of the same, or even greater magnitude, than those of the pre-euro era and more heterogeneity in co-movements.

There are different possible explanations for these interest-rate differentials. The first one is credit risk; sovereign issuers that are perceived as having a greater solvency risk, must pay investors a default risk premium. The second explanation is liquidity risk; that is, the risk of having to sell (or buy) a bond in a thin market and, thus, at an unfair price and with higher transaction costs. More explanations were possible before the introduction of the euro; in particular, expectations of exchange-rate fluctuations and different tax treatment of bonds issued by different countries were relevant. Different tax treatments were eliminated or reduced to a negligible level during the course of the 1990s. The introduction of the euro in January

1999 virtually eliminated the expectations on exchange-rate fluctuations, at least until the most recent events that might have induced some positive probability on the event of the collapse of the EMU. In the EMU period, credit risk seems to be the dominant factor as liquidity risk has a small role and it strongly co-moves with credit-risk.[2]

The global VAR (GVAR) approach advanced in Pesaran, Schuermann, and Weiner (2004, PSW) and described in Chapter 2 of this book provides a flexible reduced-form framework capable of accommodating time-varying co-movements across domestic variables and their foreign counterpart.

We propose to model spreads in the euro area via a co-integrated GVAR specification that allows for a nonlinear relation between fiscal fundamentals and government bond spreads. In particular, we concentrate on the following specification of a system of ten equations for the 10-year interest-rate spreads on German bunds for Austria, Belgium, Finland, France, Greece, Ireland, Italy, the Netherlands, Portugal, and Spain, to be estimated on monthly data:

$$\begin{aligned}\Delta\left(Y_t^i - Y_t^{bd}\right) = {} & \beta_{i0} + \beta_{i1}\left(Y_{t-1}^i - Y_{t-1}^{bd}\right) + \beta_{i2}\left(Y_{t-1}^i - Y_{t-1}^{bd}\right)^* \\ & + \beta_{i3}\left(Baa_{t-1} - Aaa_{t-1}\right) \\ & + \beta_{i4}E_t\left(b_t^i - b_t^{bd}\right) + \beta_{i5}E_t\left(d_t^i - d_t^{bd}\right) \\ & + \beta_{i6}\Delta\left(Y_t^i - Y_t^{bd}\right)^* + \beta_{i7}\Delta\left(Baa_t - Aaa_t\right) + \mathbf{u}_{it}\end{aligned}$$

$$\left(Y_t^i - Y_t^{bd}\right)^* = \sum_{j\neq i} w_{ji}\left(Y_t^j - Y_t^i\right)$$

$$w_{ji} = \frac{w_{ji}^*}{\sum\limits_{j\neq i} w_{ji}^*},\quad w_{ji}^* = \frac{1}{dist_{ji}} \text{ if } dist_{ji} < 1, 0 \text{ otherwise}$$

$$dist_{ji} = 0.5 * E_t\left(\left|b_t^j - b_t^i\right|\right)/0.6 + 0.5 * E_t\left(\left|d_t^j - d_t^i\right|\right)/3.$$

The model relates yield spreads on bunds to local fiscal fundamentals, a non-euro area exogenous variable and foreign euro-area spreads. Following Attinasi et al. (2010), we include the average for a two-year period

[2] The availability of credit default swaps (CDS) for the more recent part of the sample allows us to measure the default-risk premium component. The comparison between yield spreads on bunds and CDS spreads performed by Favero and Missale (2012) clearly indicates the non-default component if the yield spread is very small for almost all member countries.

of the expected budget balance to GDP ratio (d_t^i) and debt to GDP ratio (b_t^i). The expected variables are the European Commission Forecasts, that are released twice a year. We include in the model the differences between each country's forecast and the forecast of the same variables for Germany. The non-euro area exogenous variables is the US corporate Baa-Aaa spread, computed on the basis of the data made available in the FRED database of the Federal Reserve of St. Louis. This variable is introduced to capture the influence of time-varying risk aversion, which is a world factor commonly believed to influence euro-area credit spreads (Codogno et al., 2003; Geyer et al., 2004; Bernoth et al., 2006). Finally, we introduce a global variable that delivers country-specific common components designed to capture the impact of other countries' yield spreads on each country's spread on German Bund. In the specification of this variable we innovate with respect to the traditional approach of using trade weights (see, for example, Dées, di Mauro, Pesaran, and Smith 2007). The spreads of all foreign countries are mapped into a global country-specific factor by taking into account their 'distance' from the country considered. This distance is measured in terms of differences in fiscal fundamentals. In particular, an equally weighted average of the distance in expected deficit to GDP ratio and in expected debt to GDP ratio is considered. For aggregation purposes distances in terms of debt and deficit are rescaled by the Maastricht limits (60% for the debt to GDP ratio and 3% for deficit to GDP ratio). Countries' weights are set to zero when the distance between two countries is higher than one. The use of time-varying weights determined by the distance among fiscal fundamentals is a contribution to the existing GVAR literature that already includes weighting schemes alternative to the standard trade weights: Galesi and Sgherri (2009) propose weights based on cross-country financial flows, Dées and Vansteenkiste (2007) use weights which are based on the geographical distances among regions, whereas Hiebert and Vansteenkiste (2007) adopt weights based on sectorial input–output tables across industries, and finally Eickmeier and Ng (2012) investigate the international propagation of financial shocks via credit and securities markets by using a range of country weighting schemes for the foreign aggregates. This construction of the global spread introduces the possibility of a nonlinear relation between spreads and fiscal fundamentals and makes the global variable more volatile and therefore potentially more appropriate to capture fluctuations in domestic spreads than the global variables constructed by using trade weights.

The time-varying weights, related to the changing forecasts for fiscal fundamentals, have the potential of explaining the changing correlation of spreads discussed in the descriptive data analysis.

11.2.1 *Properties of the model*

The specified model consists of 20 equations: 10 equations for the spreads and 10 identities defining the global variables. The model is estimated on monthly data and simulated for a horizon of at most six months ahead. No equation is specified for the US (Baa-Aaa) spread and for the forecast of fiscal variables as they are taken as exogenous. The Baa-Aaa is a global non-euro-area variable that is considered as strongly exogenous. The (weak) exogeneity of the fiscal forecast can be justified on the basis of the frequency of the data. Forecasts for the fiscal variables are provided by the European Commission every six months, while the model is estimated on monthly data for the spread. The assumption of weak exogeneity is therefore justified if the current observation of the spread does not affect the forecast for the fiscal variables over the next six months, and it is also valid for simulation purposes when the model is to be used with a horizon for simulation and forecasting of less than six months. Given the time necessary to propose and vote budget laws, the absence of feedback from market conditions to the relevant legislation to determine the dynamics of fiscal variables within a period of six months seems a tenable assumption. Also, the absence of a simultaneous response of real macroeconomic variables, such as GDP growth, to financial variables is a common assumption in the monetary VAR literature. Global spreads are taken as weakly exogenous for estimation of the relevant parameters in the specification for each country spread as in the tradition of Global VAR (the global variable is an average of spreads in the euro area excluding the country for which the right-hand variable is specified). However, the absence of simultaneous feedback is imposed only contemporaneously, i.e. within the same month, and the global spreads are not taken as strongly exogenous as they dynamically depend on each country's spread when the model is simulated. The long-run equilibrium for all spreads depends nonlinearly on fiscal fundamentals for all euro-area countries and on the (Baa-Aaa) spread. The model can therefore accommodate multiple equilibria (see, for example, Calvo, 1988) relationships between each country's fiscal fundamentals and the spread on bunds. For the same level of local fiscal fundamentals a 'good equilibrium' or a 'bad equilibrium' may emerge, depending on the fiscal fundamentals of other euro-area countries; close countries in term of fiscal fundamentals matter for each country more than distant countries. As a consequence, the emergence of a 'bad equilibrium' might affect only a subset of countries, but the more countries are caught in the bad equilibrium the more likely it is that other countries will also fall in the same equilibrium.

Interaction among different euro-area spreads is allowed through three separate but interrelated channels:

1. direct dependence of each country's spreads on their associated global euro-area foreign counterparts and their lagged values—the strength of this interaction is determined by the dynamics of fiscal fundamentals and it is therefore time-varying;
2. dependence of the region-specific variables on a common global exogenous variables: the (Baa-Aaa) spread;
3. non-zero contemporaneous dependence of shocks in region *i* on the shocks in region *j*, measured via the cross-region covariances of the residuals in the behavioural equations of the system.

After model estimation and identification of the relevant shocks, impulse response analysis and model simulation can be performed. The shape of the impulse responses is determined by the changing fiscal fundamentals and the model will deliver different impulse responses when the same shocks hit the system in different periods. Given the nonlinearity of the system, impulse responses can be computed via simulation of the full system of 20 equations, and bootstrapping is the most natural approach to derive the relevant confidence intervals.[3] The model can also be used to forecast spreads up to the six-month-ahead horizon conditioning on a scenario for fiscal forecasts and the Baa-Aaa spread. The impact of fiscal packages on the short-term dynamics of the spreads can be evaluated by generating forecasts based on a baseline scenario for fiscal forecast to be compared with the scenario for fiscal forecast modified to take the effect of fiscal stabilization packages into account.

Finally, note that the nonlinear GVAR model allows for a time-varying interdependence between spreads in the euro area, where the only source of variation is fiscal fundamentals. The stability of the relation between global spreads and local spreads limits the time variation of the interdependence among country spreads, as it only allows fluctuations driven by fiscal fundamentals. In such a framework, markets do have a role as a fiscal discipline device, as the interdependence among different countries might very well change over time but only in a way related to fundamentals. The structural stability of the coefficients on the global variable is an issue of some relevance: in fact, instability of the impact on the global variable on local spreads would imply that episodes of contagion might dominate the fundamentals-driven interdependence across countries, and market sentiment might become an important driver of spreads in the presence of shocks. Following Forbes and Rigobon (2002), a significant increase in cross-market linkages after a shock to a group of countries can be defined as contagion. Contagion here is to be interpreted as a change in the relation

[3] See Favero (2012) for a full description of the relevant techniques.

between spreads in the euro area in addition to the 'natural' time-varying relation driven by fiscal fundamentals. Note that local spread shows a high degree of dependence to global spread during periods of stability. Therefore the evidence that markets continue to be highly correlated after a global shock may not constitute contagion. It is only contagion if cross-market co-movements increases significantly after the shock. The presence of contagion is identified by a time-varying interdependence. If the nonlinear GVAR specification captures correctly the fundamentals driving the spreads, then the effect of contagion, can be used to measure the impact of 'market sentiment' in driving yield differentials away from the path consistent with fundamentals. The effect of contagion can be measured within our proposed framework by introducing time-varying volatility in the GVAR specification. To parsimoniously parametrize the time-varying process for the variance–covariance matrix, Favero (2012) estimates a series of multivariate GARCH models for the spread of each country on Germany and the associated global spread. This specification allows for a time-varying conditional variance–covariance between the spread of domestic bonds on bund and the global spread relevant for each country, and it can be used to generate time-varying estimates of the impact of the global spread on the domestic spread.

11.3 The properties of the nonlinear GVAR: an illustration

The properties of the specification are illustrated via estimation, impulse response analysis, and dynamic out-of-sample simulation based on a baseline and on an alternative scenario for the exogenous variables, by considering a sample of monthly observations over the period 2000–11.

11.3.1 *Estimation*

The results of the estimation, implemented via the SURE method, are reported in Table 11.1. The model has been estimated over the euro regime for the sample 2000q1–2011q4. We have stopped estimation in April 2011, as this is the last period in which the global variable is different from zero for all countries included in the system. In fact, from May 2011 onwards as a consequence of the increased distance between Greek fiscal fundamentals and all other euro-area countries' fundamentals, the weight of Greece in the determination of the relevant global trends becomes zero for all countries and no global variables for Greece can be defined.[4] As a consequence of

[4] In principle, the estimation of the system over the full sample up to the end of 2011 could still be performed. From 2011:5 onwards the explosive behaviour of the Greek spread will not

Table 11.1. Spreads on bunds, seemingly unrelated regression, sample February 2000–April 2011, monthly data.

	BG	ESP	FIN	FRA	GRE	IRE	ITA	NL	OE	PT
β_{i0}	**0.078**	0.024	−0.030	−0.01	0.187	−**0.213**	0.066	−**0.021**	−**0.036**	0.085
	(0.020)	(0.024)	(0.021)	(0.006)	(0.236)	(0.054)	(0.050)	(0.007)	(0.0091)	(0.043)
β_{i1}	−**0.182**	−**0.12**	−**0.167**	−**0.177**	−**0.215**	−**0.08**	−0.08	−**0.233**	−**0.107**	−0.069
	(0.048)	(0.037)	(0.036)	(0.036)	(0.058)	(0.029)	(0.05)	(0.045)	(0.035)	(0.056)
β_{i2}	**0.056**	**0.114**	**0.058**	0.098	**0.987**	**0.222**	0.039	**0.031**	−0.0004	**0.365**
	(0.021)	(0.034)	(0.020)	(0.062)	(0.259)	(0.041)	(0.044)	(0.011)	(0.021)	(0.135)
β_{i3}	**0.028**	−0.013	**0.03**	**0.025**	−0.140	**0.108**	0.018	**0.047**	**0.049**	**0.105**
	(0.012)	(0.017)	(0.01)	(0.006)	(0.081)	(0.033)	(0.011)	(0.009)	(0.009)	(0.036)
β_{i4}	−0.017	−0.030	0.011	0.068	−0.262	−0.135	−0.089	**0.066**	0.023	0.366
	(0.013)	(0.039)	(0.042)	(0.051)	(0.312)	(0.080)	(0.085)	(0.026)	(0.057)	(0.282)
β_{i5}	0.007	0.015	−0.006	0.0001	0.014	−0.027	0.002	−0.010	0.0004	−0.017
	(0.011)	(0.011)	(0.008)	(0.005)	(0.039)	(0.016)	(0.010)	(0.006)	(0.007)	(0.039)
β_{i6}	**0.116**	0.017	0.085	**0.073**	**1.700**	**0.510**	**0.404**	**0.360**	**0.442**	**1.199**
	(0.028)	(0.052)	(0.044)	(0.01)	(0.280)	(0.091)	(0.047)	(0.039)	(0.056)	(0.172)
β_{i7}	**0.121**	**0.212**	**0.098**	**0.054**	0.071	0.117	**0.155**	**0.041**	0.030	−0.018
	(0.035)	(0.051)	(0.025)	(0.017)	(0.183)	(0.087)	(0.034)	(0.017)	(0.026)	(0.093)
Residuals correlation matrix										
IRE	ITA	NL	OE	PT						
BG	1									
ESP	0.458	1								
FIN	0.226	0.059	1							
FRA	0.603	0.363	0.393	1						
GRE	−0.211	0.261	0.040	−0.193	1					
IRE	0.258	0.360	0.232	0.410	0.175	1				
ITA	0.477	0.434	0.263	0.404	−0.208	0.188	1			
NL	0.094	−0.067	0.072	0.164	−0.240	−0.261	0.028	1		
OE	0.420	0.213	0.403	0.248	−0.010	0.175	0.011	−0.088	1	
PT	−0.278	0.011	−0.049	−0.186	0.249	0.176	−0.240	−0.089	−0.167	1
Adj R^2	0.127	0.196	0.171	0.231	0.318	0.442	0.440	0.475	0.473	0.361

$$\Delta\left(Y_t^i - Y_t^{bd}\right) = \beta_{i0} + \beta_{i1}\left(Y_{t-1}^i - Y_{t-1}^{bd}\right) + \beta_{i2}\left(Y_{t-1}^i - Y_{t-1}^{bd}\right)^* + \beta_{i3}\left(Baa_{t-1} - Aaa_{t-1}\right)$$
$$+\beta_{i4}E_t\left(b_t^i - b_t^{bd}\right) + \beta_{i5}E_t\left(d_t^i - d_t^{bd}\right) + \beta_{i6}\Delta\left(Y_t^i - Y_t^{bd}\right)^* + \beta_{i7}\Delta\left(Baa_t - Aaa_t\right) + \mathbf{u}_{it}$$

our definition of global variable, the spread on German bunds for a country that is distant from all other countries in the euro area by more that 60% in terms of the debt to GDP ratio and more than 3% in terms of the deficit to GDP ratio becomes insulated from the general euro-area dynamics. The estimation results show that there is evidence for a long-run solution for each spread that depends on the level of the Baa-Aaa spread and the global variable. This evidence is statistically significant for all countries, with milder evidence for Italy and Portugal. Fiscal fundamentals seem to affect spreads only nonlinearly through the global variable, as there is no evidence for a linear impact of debt to GDP and deficit to GDP forecasts on the spreads. Fluctuations in the global variables and the Baa-Aaa spreads are also in general significant in determining the short-run dynamics of the spreads. However, changes in the Baa-Aaa spread do not impact significantly on the spread of bunds in the case of Ireland, Portugal, and Austria, while changes in the global spread do not affect the Spanish and the Finnish spread. Overall, there is a sizeable heterogeneity of coefficients across countries. This heterogeneity speaks against imposing panel restrictions when the system is estimated. Finally, it is worth noting that on top of the interdependence introduced by the global variable and the Baa-Aaa there is an additional channel captured by the variance–covariance matrix of residuals that witnesses the presence of significant cross-correlation among the residuals of the equations for different spreads.

11.3.2 *Impulse response analysis*

The specification of a nonlinear GVAR model for the spreads has interesting implications for the implementation of the standard way of examining economic interaction: i.e. impulse responses. Impulse response analysis examines the effect of a typical shock, usually one-standard deviation, on the time path of the variables in the model. In the nonlinear GVAR specification, impulse responses are not constant over time, as they depend on the time-varying distance between fiscal fundamentals across different countries. To illustrate the relevance of this point for the econometric modelling of the dynamic properties of our model consider the case of Ireland and Greece. At the beginning of 2005 the fiscal fundamentals in Greece were so different from the Irish one that the weight of Greece in the determination of the global spread for Ireland was zero (the expected debt to GDP ratio over the two following here stood at 32% and 111%, respectively, while the

affect other spreads as a consequence of the insulation of Greece in the construction of global variables. However, it would be impossible to bootstrap the system using the entire sample because Greece would not be insulated from the rest of Europe before April 2011 and therefore the explosive behaviour of the Greek spread will affect the entire system making it unstable under simulation.

expected deficits over GDP ratio were 0.5% and 3.3%). Over time the Irish fiscal fundamentals have converged remarkably to the Greek ones and at the beginning of 2010 the weight of the Greek spread in the determination of the global spread for Ireland became as high as 0.6, as the Irish debt to GDP ratio rose to 90% of GDP, while the same figure for Greece stood at 130 per cent and the expected deficit to GDP ratio became very close, with the Irish figure of 14.7% being higher than the Greek figure of 12.5%. Dynamic simulation of our model should reflect these facts through the heterogeneity of impulse response functions in the two periods.

Impulse response functions can be computed by considering innovations to observables, such as the spreads of 10-year Greek bonds on German bunds or the US Baa-Aaa spreads, or to unobservables, i.e. the 'structural' shocks to some of the variables included in the VAR. Computing impulse responses to unobservables requires some identification assumption, and the orthogonality of structural shocks allows us to consider the effect of each identified shock in isolation. The study of the response to the system to an innovation in observables does not require any identification assumption but the contemporaneous linkages between shocks must be modelled. We illustrate the properties of our model by considering the effect of a 50-basis-point innovation in the spread of Greek bonds on bunds on the spread of Irish bonds on bunds, using the generalized impulse response functions, GIRFs, discussed in Garratt et al. (2006), which exploits the estimated error covariances to model the contemporaneous linkages across shocks.[5] This requires no identifying assumptions, although the non-orthogonality of the innovations may pose some difficulties in the structural interpretation of the shocks. GIRF seems to be more appropriate when, as in our case, the primary focus of the analysis is the description of the transmission mechanism rather than the structural interpretation of shocks.

The effect of the shock we are studying can be interpreted as the effect on the variables in the model of an intercept adjustment to the particular equation shocked.

Figure 11.3 illustrates a significant heterogeneity in the effect of a 50-basis-point innovation in the Greek spread on the Irish spreads: the effect in 2010, is twice as strong as in 2005 (with impact multiplier larger than one in 2010 where the response in the Irish spreads stands at 70 basis points against an initial response of 30 basis points in 2005) and the difference is statistically significant.

[5] Within this framework the simultanoeous response of each country spread to an innovation in the spread of Greek bonds on bunds is estimated as the expectations of the innovation in each country spread conditional on the realization of the innovation in the Greek–German spread.

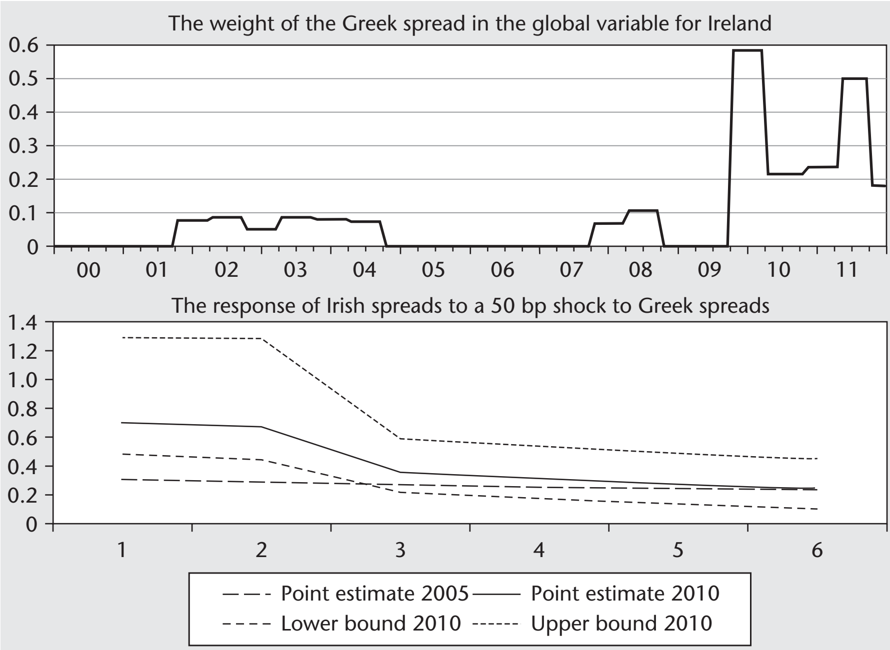

Figure 11.3. Cross-country impact on spreads for Ireland.

11.3.3 *Dynamic simulation*

The non-linear relation between fiscal fundamentals and 10-year government bond spreads embedded in the nonlinear GVAR specification could be exploited to simulate the dynamic effect on spreads of fiscal policy packages. At the end of 2011, the Italian parliament approved a fiscal stabilization package proposed by the government led by the newly appointed prime minister Mario Monti, which implemented a correction in the deficit to GDP ratio of about 2% and to a stabilization of the debt to GDP dynamics. The nonlinear GVAR model allows us to evaluate the impact of this stabilization package on the BTP-bund spread. We do so by simulating the model forward for six months over the period November 2011–May 2012. Two scenarios for simulations are considered: a baseline scenario in which the projected deficit to GDP ratio and debt to GDP ratio take the values forecasted by the European Commission in October 2011 and stands respectively at 1.75% and 119.6%, and an alternative scenario in which the 2% correction of the Monti stabilization package is used to project the deficit to GDP and debt to GDP ratio for Italy. The European Commission forecasts for all the other countries are left unaltered in the baseline and the alternative scenarios; also, the Baa-Aaa spread is kept constant at about 100 basis points in the two alternative

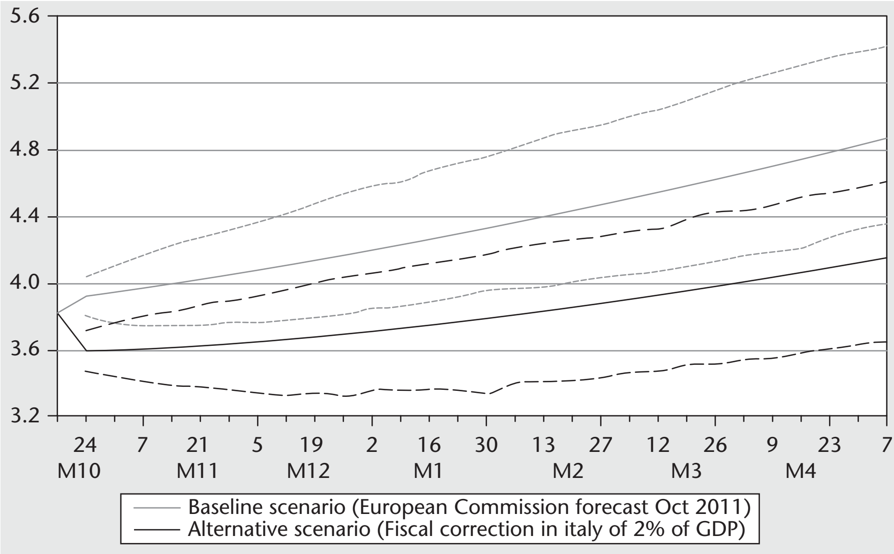

Figure 11.4. The effect on the 10-Y BTP-bund spread of a fiscal adjustment in Italy.

simulations. Figure 11.4 reports the simulated spread of the Italian BTP on bund under the two scenarios.

The dynamic simulation of our model suggests an impact effect of the stabilization package of a reduction in the spread of about 40 basis points (with the spread standing at just below 400 basis points in the baseline scenario and at about 360 basis points in the alternative stabilization scenario), which becomes about 80 basis points after six months (with the spread standing at 490 and 410 basis points, respectively). The impact effect is mainly attributable to the modification in the global spread relevant for Italy as a consequence of the change in the distance between Italy and the other euro-area countries caused by the stabilization package; such a modification also affects the relevant dynamics that lead to a further reduction in the spread over time.

11.4 Conclusions

Instability in the co-movements among bond spreads in the euro area is an important feature for dynamic econometric modelling and forecasting. We propose to model such instability via a GVAR model that maps the spreads of all other countries into a global variable relevant to determine the dynamics of each country spread by taking into account the 'distance' from the country considered. Distance is measured in terms of differences in fiscal fundamentals: the expected deficit to GDP ratio and in the expected debt to GDP ratio. The model naturally accommodates the possibility of multiple equilibria in the relation between default premia and fiscal fundamentals. Different spreads might correspond to the same level of domestic fiscal fundamentals, as the mapping between spreads and local fiscal fundamentals is affected by other euro-area countries' fiscal fundamentals. The estimation of the model reveals a significant nonlinear relation between spreads and fiscal fundamentals that generates a time-varying impulse response function of local spreads to shocks in other euro-area countries' spreads. The GVAR framework can also be naturally applied to the analysis of the dynamic effects of fiscal stabilization packages on the cost of government borrowing. The simulation of the GVAR model for the evaluation of the fiscal stabilization package introduced by the Monti government in Italy at the end of 2011 estimates its effect on the spread in a reduction of about 100 basis points in the semester following its announcement. The results of estimation and simulation of the nonlinear GVAR model has relevant implications for the assessment of the relation between fiscal policy and spreads and for the design of financial instruments capable of insulating the cost of sovereign borrowing from 'market sentiment' (see Favero and Missale 2012).

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12

The international spillover of fiscal spending on financial variables*

Christiane Nickel and Isabel Vansteenkiste

12.1 Introduction

This chapter studies the international spillover effects of fiscal shocks. The focus of the analysis is on the impact of fiscal spending shocks on financial variables (namely equity prices and government and corporate bond yields). In a world with increasingly integrated capital markets, fiscal policy of one country is more likely to impact agents across the world. This may occur during normal times in the usual conduct of fiscal policy. These spillovers are however, even more apparent during times of crises. In this context, recent events have made the presence of fiscal spillovers clear. The difficult fiscal situation of several euro-area economies, such as Greece, but also Portugal, Spain, and Ireland, resulted in an increase in global risk aversion (as measures by the VIX index), a fall in equity prices, and rising interest-rate spreads, indicating that fiscal spillovers are indeed at work.[1] However, in spite of this, to our knowledge, few papers have to date considered the implications on financial variables. In general, these analyses have been conducted mostly

* The views expressed in this chapter are those of the authors and do not necessarily reflect those of the European Central Bank (ECB). The authors would like to thank Ad van Riet and the participants of the DNB/IMF workshop on Preventing and Correcting Macroeconomic Imbalances in the euro area for their helpful comments. Any remaining errors are the sole responsibility of the authors.

[1] For an exposition of the behaviour of government spreads of euro-area countries during the global financial crisis, see Attinasi et al. (2010).

in the context of the earlier years of the European monetary union, with a focus on the decrease in government bond spreads between Germany and the other member states.

In this chapter, we go beyond the existing literature by extending the country scope and the variables of interest. To do so, we rely on the global vector autoregression (GVAR) methodology of Dées, di Mauro, Pesaran, and Smith (2007) and Pesaran, Schuermann, and Weiner (2004).

Our GVAR is estimated on the basis of six variables: fiscal spending, real GDP, inflation, equity prices, government bond yields, and corporate bond yields. To analyse the spillover impact of fiscal shocks on financial and real-side variables, we use quarterly data for eight countries: France, Germany, Italy, Spain, Sweden, the UK, Japan, and the US. The country selection relates to gauging spillovers across the most important countries across the globe; however, our country selection was also constrained by data availability as we considered a long time span at a high frequency (namely from 1980q1–2008q4).[2]

The remainder of the chapter is as follows: section 12.2 describes the model approach and data; section 12.3 discusses the model test and estimation results, and presents the dynamic properties of the model; and section 12.4 concludes.

12.2 The model and data

To determine the role of fiscal policy spillovers we estimate a GVAR model, as in Dées, di Mauro, Pesaran, and Smith (2007) and Pesaran, Schuermann, and Weiner (2004). In our case, the GVAR is estimated on the basis of six variables: fiscal spending (*fisc*), real GDP (y), inflation (p), equity prices (s), government bond yield (*gi*), and the corporate bond yield (*ci*) (see Appendix A for more information on data definitions and sources). To analyse the spillover impact of fiscal shocks on financial and real-side variables, we use quarterly data for eight countries: France, Germany, Italy, Spain, Sweden, the UK, Japan, and the US. The country selection relates to gauging spillovers across the most important countries across the globe; however, the country selection was also constrained by data availability as we considered a long time span at a high frequency (namely from 1980q1–2008q4). One important input in the calculation of the GVAR model is to construct the

[2] The estimation sample ends at the start of the global financial crisis (i.e. 2008q4) as there is a clear structural break, in particular for real GDP growth. However, when updating the estimations up to 2011q4, the main results for the fiscal and financial shocks are broadly unchanged.

country-specific starred variables. While in theory several possible weighting schemes could be considered, the practical choice of a country-specific weighting scheme is unfortunately conditioned by data availability. Trade weights are one widely used method of linking countries through a directly observable and standard set of weights, and are used to generate country-specific averages of those of other countries. They are obtained as the sum of exports and imports of goods in value terms over the period 2000–08 based on IMF Direction of Trade Statistics data, rescaled so that the country weights sum to one.

One important consideration in analysing the extent of spillovers is in this context considering the correlation between each variable and its country-specific foreign counterpart (i.e. the starred variables). The results are shown in Table 12.1. As can be seen, while the correlation between financial variables is extremely high (in particular for government and corporate bond yields, where the correlation is almost always above 90%), it is much lower for real GDP and inflation, but even less so for real government consumption. Indeed, fiscal spending seems to be particularly uncorrelated across countries over the sample period we consider (also considering the correlation in real GDP), suggesting different fiscal approaches to government consumption across the countries.

Table 12.1. Average correlation between country-specific and foreign variables.

	Real GDP growth	Real gov. cons. growth	Inflation
France	0.66	0.09	0.90
Germany	0.44	−0.08	0.62
Italy	0.53	0.17	0.91
Japan	0.34	0.05	0.73
Spain	0.30	−0.06	0.86
Sweden	0.51	0.18	0.76
UK	0.46	−0.15	0.82
US	0.34	0.05	0.77

	Corporate bond yield	Government bond yield	Equity return
France	0.96	0.97	0.82
Germany	0.88	0.95	0.79
Italy	0.97	0.98	0.69
Japan	0.94	0.96	0.57
Spain	0.92	0.97	0.35
Sweden	0.92	0.95	0.82
UK	0.97	0.97	0.83
US	0.92	0.94	0.76

Note: The series show the results for the period 1980q1–2008q4.

12.3 Estimation results

12.3.1 *Contemporaneous effects of country-specific foreign variables on their domestic counterparts*

Table 12.2 presents the contemporaneous effects of the starred variables on their counterparts for robust *t*-ratios, computed using White's heteroscedasticity consistent variance estimator.[3] These values can be interpreted as impact elasticities between domestic and starred variables. They are particularly informative as regards the linkages across countries. Focusing on government consumption (*fisc*), for instance, we can see that a 1% change in the other countries' weighted government consumption in a given quarter leads to a statistically significant increase of 0.22% in government consumption in Italy in the same quarter. However, in line with the finding above, the results indicate that in most cases there is no significant contemporaneous effect of foreign fiscal spending on the domestic counterpart.

12.3.2 *Impulse responses*

Due to the simultaneous nature of the country-specific models, a more satisfactory approach to the analysis of dynamics and interdependencies

Table 12.2. Contemporaneous effects of foreign variables on their domestic counterparts in state-specific models.

	y	π	s	fisc	gi	ci
France	0.47	0.49	1.06	0.05	0.20	0.81
t-ratio	(7.30ˆ)	(4.94ˆ)	(17.57ˆ)	(1.48)	(1.65*)	(6.94ˆ)
Germany	0.91	0.80	0.99	−0.14	0.90	0.31
t-ratio	(4.67ˆ)	(6.00ˆ)	(12.04ˆ)	(−0.70)	(3.71ˆ)	(2.01ˆ)
Italy	0.53	0.11	1.09	0.22	0.07	1.39
t-ratio	(5.06ˆ)	(1.09)	(9.66ˆ)	(1.72*)	(0.25)	(4.70ˆ)
Japan	0.34	0.46	0.63	0.01	0.33	0.40
t-ratio	(2.00ˆ)	(3.63ˆ)	(5.51ˆ)	(0.04)	(1.27)	(1.30)
Spain	0.49	0.50	0.46	−0.30	0.07	0.64
t-ratio	(2.81ˆ)	(2.94ˆ)	(2.75ˆ)	(−0.32)	(0.15)	(1.44)
Sweden	1.07	0.81	1.17	0.25	0.14	0.69
t-ratio	(5.57ˆ)	(4.00ˆ)	(13.16ˆ)	(1.85*)	(0.50)	(2.06ˆ)
UK	0.51	0.60	0.75	−0.25	0.51	0.91
t-ratio	(4.98ˆ)	(3.33ˆ)	(15.37ˆ)	(−1.72*)	(1.74*)	(3.30ˆ)
US	0.28	1.13	0.64	0.06	0.29	0.90
t-ratio	(2.30ˆ)	(9.34ˆ)	(9.97ˆ)	(0.43)	(1.76*)	(4.40ˆ)

Note: ˆ indicates significance at the 5% level, * at the 10% level.

3 Note that we have run the standard tests for the model, before considering the estimation. To determine the order of the VAR we have used the AIC criterion, and the trace test was used to determine the number of co-integrating relationships. We also checked whether the variables are $I(1)$ and the weak exogeneity of the country-specific foreign variables. In all of the cases the weak exogeneity tests turned out to be statistically significant.

(both on impact and over time) among the various factors would be via impulse response functions computed from the solution to the GVAR model. In our analysis we rely on the computation of generalized impulse response functions (GIRFs) as advanced by Koop, Pesaran, and Potter (1996) for non-linear models and developed further in Pesaran and Shin (1998) for vector error-correcting models. Although the approach is silent as to the specific structural factors behind the changes, the GIRFs can be quite informative about the dynamics of the transmission of shocks.

Impulse responses are presented for 40 quarters following the imposition of a shock. Charts 1 to 4 display the bootstrap estimates of the GIRFs.[4]

We investigate in this chapter the implication of three different shocks:

- the impact of a shock to government consumption on government bond yields;
- the impact of a shock to government bond yields on corporate bond yields;
- the impact of a shock to government consumption on equity prices.

We consider in all cases the impact of shocks originating from four countries; namely Germany, the US, Spain, and Italy. The figures in the following subsections contain the estimated country responses.

12.3.2.1 SHOCK TO GOVERNMENT CONSUMPTION: IMPACT ON GOVERNMENT BOND YIELD

Figures 12.1–12.4 contain the generalized impulse responses from a 10% shock to German, US, Spanish, and Italian government consumption, respectively on government bond yields. In each figure, the left-hand chart shows the domestic government bond yield response to the shock while the right-hand side shows the dynamic response of other countries in the GVAR.

Overall, in all cases, the domestic government bond yield response to a government consumption shock is positive and statistically significant. Moreover, in all cases except Italy, the response reaches a peak after around 3–5 quarters. By contrast in Italy, the peak response occurs instantaneously. The largest response to a shock in government consumption is in Spain where at the peak, government bond yields are almost 20 basis points above the baseline. By contrast, the weakest response is in Italy, where they are at most eight basis points higher than the baseline.

Looking at the spillovers to the other countries in the sample, we can split the results into two distinct groups. First, we consider the shocks emanating from the US and Germany. These are countries with a large,

[4] The computations are carried out using a sieve bootstrap procedure, as reported in Dees, di Mauro, Pesaran, and Smith (2007).

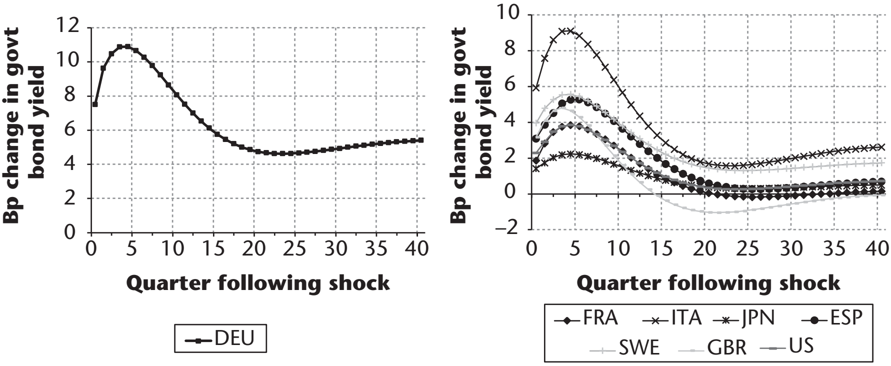

Figure 12.1. Impact of a 10% shock to government consumption in Germany to government bond yields.

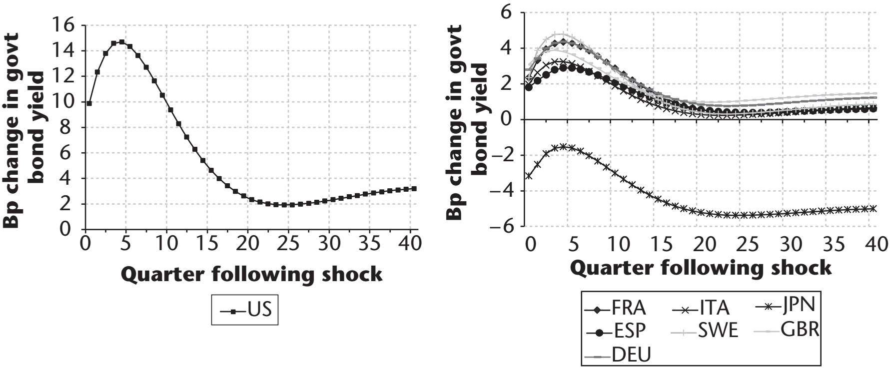

Figure 12.2. Impact of a 10% shock to US government consumption on government bond yields.

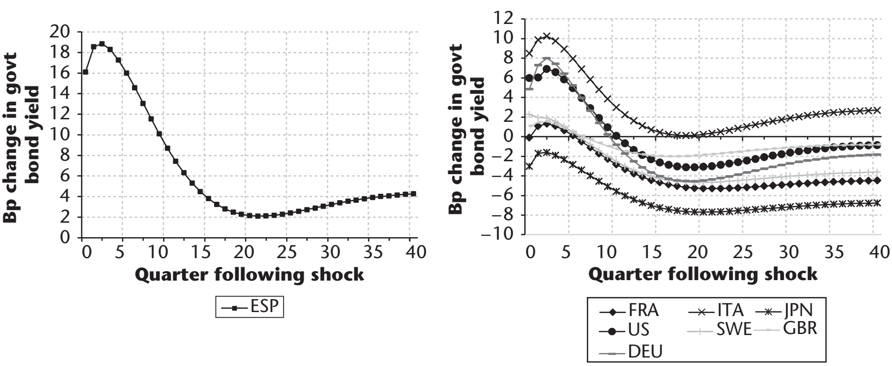

Figure 12.3. Impact of a 10% shock to Spanish government consumption on government bond yields.

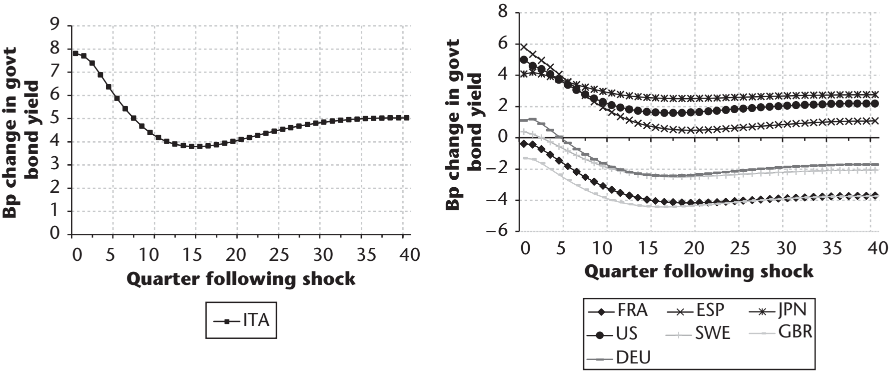

Figure 12.4. Impact of a 10% shock to Italian government consumption on government bond yields.

liquid financial sector, where fiscal policy is perceived to be sustainable. As a result investing in the goverment bond market of these countries is broadly perceived as being risk-free. In these cases, the impact of fiscal spending shocks on government bond yields in other countries is generally positive and in many cases also statistically significant. Similar results are found for the UK.[5] Such a finding would suggest that a fiscal spending shock leads to global increases in interest rates. In both the case of Germany and the US, at the peak, government bond yields are around four basis points higher than in the baseline for most countries. By contrast, when we consider a government spending shock emanating from a peripheral country (i.e. Spain or Italy), the impact on government bond yields in the US and Germany is actually negative and statistically significant. Indeed, a 10% shock to government consumption in Spain lowers French and German government bond yields by up to five basis points. The same shock emanating from Italy lowers French and German government bond yields by up to four and two basis points, respectively. At the same time, a government spending shock in the peripheral countries increases significantly bond yields in other peripheral countries. In more detail, government bond yields in Italy increase by over 10 basis points at its peak after a Spanish government spending shock. Spanish government bond yields instantaneously rise by six basis points after a 10% government spending shock in Italy. This could suggest that fiscal shocks in countries where there is a concern regarding the long-run sustainability and potentially the soundness of the fiscal policy framework may be resulting in capital outflows to 'safe havens'.

[5] The results for the UK are not shown in the figures in this chapter. They are available upon request from the authors.

12.3.2.2 SHOCK TO GOVERNMENT BOND YIELD: IMPACT ON CORPORATE BOND YIELD

Next we can consider the generalized impulse responses from a 100-basis-point shock to German, US, Spanish, and Italian government bond yields on corporate bond yields. Here we find that in all cases, the domestic corporate bond yield response to a government bond yield shock is large, positive, and statistically significant. Indeed, the responses range (at their peaks) between 13 and 49 basis points. The largest corporate bond yield response to a shock in government bond yields is in Italy, whereas the most muted response is in Germany. In the US and Spain, the responses peak instantaneously, whereas in the case of Germany and Italy they peak after two and eight quarters, respectively.

Looking at the spillovers to the other countries in the sample, we can split the results into two distinct groups. Shocks that emanate from countries where the government bond is perceived as risk-free (such as Germany and the US, but also the UK) have statistically significant spillover effects to corporate bond markets in other countries. In particular in the case of the US, this impact is large, with a government bond yield shock of 100 basis points resulting in an instantaneous corporate bond yield increases of 10 basis points in the other countries in the sample. By contrast, shocks stemming from countries with relatively small financial markets, such as Italy and Spain, result in insignificant responses in other countries.

12.3.2.3 SHOCK TO GOVERNMENT CONSUMPTION: IMPACT ON EQUITY PRICES

Finally, we analyse the generalized impulse responses from a 10% shock to German, US, Spanish, and Italian government consumption on equity prices. From a theoretical point of view, Tobin (1969), in his general equilibrium approach of the financial sector, highlighted the role of stock returns as the linkage between the real and the financial sectors of the economy and showed how both money growth and budget deficits can have an important impact on stock returns (see also the theoretical discussion/models put forth by Blanchard, 1981). Based on theory and empirical evidence, however, the expected directional impact of the budget deficit on stock returns is unclear. On the one hand, government budget deficits may exert upward pressure on the (nominal) interest rate (or the discount rate, as applied to the firm) which, in turn, lowers expected returns (as the risk premium increases; see Geske and Roll, 1983). Geske and Roll also note that increases in risk premia, due to federal deficits, expose investors to an uncertainty and thus further confound the equity market. In addition, fiscal spending shocks that lead to a permanent and substantial increase in government debt or signal less sound fiscal behaviour are typically related with decreases in stock market prices (Ardagna, 2009). On the other hand, Keynesian effects of fiscal spending shocks should boost consumption and growth and through this channel create better earnings expectations.

Looking at our empirical results of the domestic equity market responses to a government spending shock, we can yet again split the results into two distinct groups: first, the large countries that pursue a perceived sustainable fiscal policy over our sample period (i.e. between 1980q3 and 2008q4), such as Germany and the US; and second, the smaller countries where the bond markets are not perceived to be risk-free, namely Spain and Italy. In the first group, the impact of a fiscal spending shock on equity prices is statistically significant and positive. In more detail, in the case of Germany, at the peak equity prices increase by almost 4%, while in the US they increase by around 2.5%. By contrast, in Spain a 10% increase in government spending lower equity prices by at most 5% compared with the baseline and in Italy by around 2%.

In terms of spillovers to the other countries, spending shocks in Germany and the US have positive spillover implications for other economies, although they are not statistically significant in most cases. Shocks stemming from Italy and Spain have small, insignificant spillover effects to other countries.

12.4 Concluding remarks

In this chapter, we have studied the international spillover effects of fiscal shocks. The focus of the analysis was on the impact of fiscal spending shocks on financial variables (such as equity prices and government and corporate bond yields). To do so, we have relied on the GVAR methodology of Dēes, di Mauro, Pesaran, and Smith (2007) and Pesaran, Schuermann, and Weiner (2004).

The GVAR was estimated on the basis of six variables: fiscal spending, real GDP, inflation, equity prices, government bond yields, and corporate bond yields. To analyse the spillover impact of fiscal shocks on financial and real-side variables, we use quarterly data for eight countries: France, Germany, Italy, Spain, Sweden, the UK, Japan, and the US. The country selection relates to gauging spillovers across the most important countries across the globe; however, our country selection was also constrained by data availability as we considered a long time span at a high frequency (namely from 1980q1–2008q4).

Our results illustrate that the fiscal policy of the large issuing countries with perceived risk-free government bonds matters not only for the countries themselves but also internationally. Since these countries (e.g. the US and Germany) are recognized as 'safe havens' they benefit from relatively lax fiscal policies in other countries in that their government and corporate bond yields go down and equity prices go up. In turn, peripheral countries are punished for relatively lax fiscal policies—not only do they punish their own financial markets but also the financial markets of other peripheral countries. These findings underline the importance of a responsible fiscal policy conduct of safe haven (or anchor) countries for the rest of the world.

Our results also highlight that there are strong financial market interlinkages between the corporate and the government sectors. In peripheral countries the corporate sector (both in terms of bond markets but also equity markets) suffers from increased government spending. Movements of government bond spreads in large 'safe haven' countries have significant impact on the corporate bond yields of the periphery. By contrast, shocks to the government bond yields in relatively small financial markets do not have a significant impact on other countries.

Appendices

A Data sources

CONSUMER PRICE INFLATION
Definition: consumer price index.
Units: Index.
Source: national sources, except France and UK: IMF.

REAL GROSS DOMESTIC PRODUCT
Definition: national account chained domestic currency seasonally and working day adjusted series.
Units: chained, domestic currency.
Source: national sources.

REAL GOVERNMENT CONSUMPTION
Definition: national account chained domestic currency seasonally and working day adjusted series.
Units: Chained, domestic currency.
Source: national sources.

EQUITY PRICES
Definition: MSCI Share Price Index with net dividend, in local currency, end of period.
Units: Index.
Source: Haver Analytics.

GOVERNMENT BOND YIELD
Definition: 10-year benchmark yield.
Units: average %.
Source: National Central Banks.

CORPORATE BOND YIELD
Definition: Long-term corporate bonds of investment grade (AAA to BBB).
Units: average %.
Source: Global Financial Database.

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Part III

Regional applications

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13

China's emergence in the world economy and business cycles in Latin America*

Ambrogio Cesa-Bianchi, M. Hashem Pesaran, Alessandro Rebucci, and TengTeng Xu

13.1 Introduction

As vividly illustrated by the impact of the recent global crisis on Latin America, the international business cycle is very important for the region's economic performance. The world economy, however, has undergone profound structural changes over the past two to three decades because of globalization and the emergence of China, India, and other large developing economies (including Mexico and Brazil in Latin America) as global economic players. As a result, the transmission mechanisms of the international business cycle to Latin America may have changed.

This chapter focuses on how changes in trade patterns between China and the rest of the world may have affected the transmission of the international business cycle to Latin America. Specifically, we investigate empirically how shocks to gross domestic product (GDP) in China and the US are transmitted to Latin America, conditional on alternative configurations of cross-country linkages in the world economy. We focus on China because its trade linkages with Latin America and the rest of the world have undergone the most dramatic shift over the period we consider. We focus on the US because this country remains the largest trading partner of the Latin American region as

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a whole and, historically, has been the major source of external shocks for Latin America. To complement this analysis, we also consider a GDP shock to the Latin American region itself and to emerging Asia (excluding China and India) because the analysis of these shocks helps shed light on the ongoing debate about the decoupling of emerging markets' business cycle from that of advanced economies.

A novel, methodological contribution of this chapter is to set up and estimate a GVAR model in which the country-specific foreign variables are constructed with time-varying trade weights, while the GVAR is solved with time-specific counterfactual trade weights. Specifically, we simulate GDP shocks in the GVAR model using trade weights at different points in time. The use of time-varying weights is important in our application not only because it allows us to account for the fast evolution of trade relations in the world economy, but more generally because it enhances parameter stability, which in turn supports more reliable counterfactual simulation exercises.

In our application, the GVAR model is applied to 25 major advanced and emerging economies plus the euro area, covering more than 90% of of world GDP. This sample includes five large Latin American economies: Argentina, Brazil, Chile, Mexico, and Peru. The data set is quarterly, from 1979q2 to 2009q4, thus including both the recession of 2008–09 and the first few quarters of the global recovery.[1]

The main results of the empirical analysis are fourfold. First, the long-run impact of a Chinese GDP shock on the five Latin American economies has increased dramatically (by three times) since the mid-1990s. Second, and consistent with the previous result, the long-run effect of a US GDP shock on Latin America has halved over the same period, with even sharper declines in the short term. Third, the transmission of domestic shocks originating in Latin America or the rest of emerging Asia (excluding China and India) has not changed over the period. Finally, the results predict that the increased impact of a Chinese GDP shock on Latin America owes as much to indirect effects, which are associated with stronger trade linkages between China and Latin America's largest trading partners (namely, the US and the euro area), as to direct effects that stem from tighter trade linkages between China and Latin America, boosted by the decade-long boom in commodity prices.

These findings have important policy implications for Latin America. First, they help to explain why these five Latin American economies recovered much faster than initially anticipated from the recent global crisis. The evidence shows that Latin American growth owes more to a fast-growing econ-

[1] The data set and the GVAR code used for our analysis are available online at <https://sites.google.com/site/gvarmodelling/>.

omy that enacted a powerful fiscal stimulus during the global crisis (China), and relatively less to the economy that was at the epicentre of the crisis (the US). Had the trade linkages been those prevailing in the mid-1990s, the region would have suffered a much sharper downturn than it actually experienced. This evidence also suggests that the so-called decoupling found in the existing literature might be related to the emergence of China as an important source of world growth, as opposed to a widespread decoupling of business cycles in emerging and advanced economies.[2] Second, the results point to hidden vulnerabilities. Latin America remains a small, open economy vulnerable to external shocks, without the necessary weight to affect the international business cycle with its own growth dynamics. While the changes documented here have had positive, stabilizing effects on Latin America's business cycle during the recent global crisis, they predict negative, destabilizing effects if and when China's growth begins to slow significantly, especially if this happens before the US and the euro area have fully recovered from the global crisis.

The rest of the chapter is organized as follows. In the next section, we review how the trade linkages between China and the rest of the world, particularly Latin America, have evolved over time, thus justifying the specific set of trade matrices we use in the counterfactual simulations. We then briefly describe the GVAR model that we use, discuss the estimation and testing of the GVAR model, and report the counterfactual simulation results. The final section concludes.

13.2 The changing weight of China in Latin America and world trade

The importance of China for Latin America's trade has tremendously increased over the past 30 years. The take-off of China's trade with Latin America, however, starts only in the mid-1990s, with little or no change in the previous decade.[3]

Moreover, growing bilateral trade linkages between China and Latin America are also associated with more synchronized business cycles over the past 15 years or so.[4] To see this, we computed a rough measure of business cycle synchronization, namely a 10-year rolling window correlation between Latin

[2] See, for example, Kose and Prasad (2010).

[3] The changing economic relationship between China and Latin America is discussed in Devlin, Estevadeordal, and Rodríguez-Clare (2006).

[4] As mentioned in the introduction, the five Latin American countries included in our sample are Argentina, Brazil, Chile, Mexico, and Peru.

American and Chinese GDP growth.[5] In 2009, the average rolling correlation for Latin America was four times higher than in 1995, increasing from 0.12 to 0.61. Furthermore, all five Latin American countries considered display a pattern similar to the regional one.[6]

While China is undoubtedly more important for Latin America's business cycle now than 15 years ago, how much more important is it? In particular, does it affect the cycle through its direct, bilateral trade linkages or through other indirect channels of interdependence? For instance, Calderón finds that China affects Latin America's business cycle mostly via its demand for commodities.[7] Consequently, the decade-long commodity price boom might be inflating the bilateral trade shares between China and Latin America. Other potentially important indirect channels of influence are related to international capital flows and China's exchange rate regime.[8]

The available trade statistics confirm that China has played an increasing role over the past 15 years not only directly, but also indirectly via its increased importance for Latin America's traditional and largest trading partners, such as the US and the euro area. Tables 13.1 and 13.2 report a complete set of trade shares for the US, the euro area, Japan, China, the five Latin American countries in our sample, and the rest of the world at two different points in time, 1995 and 2009.

The tables measure integration by total trade, as opposed to exports only.[9] Table 13.1, which features the major trade blocs, shows that the US and the euro area continue to be Latin America's largest partners by a sizable margin: at the end of 2009, the US and the euro area together accounted for more than 60% of total Latin American trade (the US 51% and the euro area 15%), after declining from almost 80% in 1995 (when US and euro area weights were 60% and 18%, respectively). The table further shows that China's emergence as a global trade power has affected Latin America's largest trading partners: China's share in total trade of the US, the euro area, and Japan grew from 5%, 4%, and 9% in 1995, respectively, to 18%, 15%, and 26% in 2009. Finally, when the trade bloc shares are disaggregated by country

[5] Latin America's regional GDP growth is calculated as a weighted average of individual countries' GDP using PPP-GDP weights averaged over the period 2006–08 (sourced from the World Bank's World Development Indicators database).

[6] Calderón (2008) reports similar evidence (through year-end 2004).

[7] Calderón (2008).

[8] See Cova, Pisani, and Rebucci (2010) and Izquierdo and Talvi (2011) for a more detailed discussion.

[9] The trade share of country *i* in country *j*'s total trade is defined as the sum of country *i*'s imports from country *j* and exports to country *j*, divided by the sum of country *j*'s total merchandise imports and exports. The available trade statistics for the relevant countries and time periods only cover trade in goods, thus omitting trade in services. Also, the trade statistics are net of transit trades.

Table 13.1. Trade shares for major trading blocs in 2009 and 1995.[a]

Year and trading bloc	*US*	*Euro area*	*Japan*	*China*	*Latin America*
A. 2009					
US	—	0.17	0.18	0.22	0.51
Euro area	0.15	—	0.11	0.18	0.15
Japan	0.07	0.05	—	0.15	0.04
China	0.18	0.15	0.26	—	0.12
Latin America	0.18	0.06	0.03	0.05	—
Rest of the world	0.42	0.58	0.42	0.39	0.18
Total	1.00	1.00	1.00	1.00	1.00
B. 1995					
US	—	0.19	0.31	0.21	0.60
Euro area	0.16	—	0.13	0.17	0.18
Japan	0.17	0.09	—	0.30	0.07
China	0.05	0.04	0.09	—	0.02
Latin America	0.13	0.05	0.03	0.02	—
Rest of the world	0.50	0.63	0.43	0.29	0.13
Total	1.00	1.00	1.00	1.00	1.00

Source: International Monetary Fund (IMF), Direction of Trade Statistics.
a. The Latin American bloc comprises the five countries in our sample (Argentina, Brazil, Chile, Mexico, and Peru). The trade share of country *i* with respect to country *j* is defined as the sum of country *i*'s imports from country *j* and exports to country *j* divided by the sum of country *i*'s total imports and exports. They are displayed in columns by country such that a column sums to one.

Table 13.2. Trade shares for Latin American countries in 2009 and 1995.[a]

Year and trading partner	*Argentina*	*Brazil*	*Chile*	*Mexico*	*Peru*
A. 2009					
US	0.12	0.17	0.20	0.70	0.25
Euro area	0.17	0.23	0.16	0.07	0.14
Japan	0.02	0.05	0.08	0.02	0.06
China	0.13	0.16	0.18	0.06	0.16
Other Latin American	0.43	0.17	0.20	0.03	0.20
Rest of the world	0.13	0.21	0.18	0.12	0.18
Total	1.00	1.00	1.00	1.00	1.00
B. 1995					
US	0.16	0.25	0.23	0.83	0.29
Euro area	0.26	0.28	0.21	0.06	0.22
Japan	0.03	0.08	0.14	0.03	0.08
China	0.03	0.03	0.02	0.00	0.05
Other Latin American	0.39	0.18	0.20	0.02	0.19
Rest of the world	0.13	0.18	0.19	0.06	0.18
Total	1.00	1.00	1.00	1.00	1.00

Source: IMF, Direction of Trade Statistics.
a. Trade weights are computed as shares of exports and imports. They are displayed in columns by country such that a column sums to one.

(Table 13.2), China's share of total trade surged in all the Latin American countries except Mexico (which recorded only a moderate increase) over the same period, and this shift mostly occurred at the expense of the US and the euro area.

This stylized evidence suggests that China today might be affecting Latin America's business cycle not only via its stronger direct trade linkages, but also through its stronger indirect linkages with the region's main traditional trading partners. In the rest of the chapter, we quantify how these changes in the geographical composition of trade have affected the transmission of specific shocks to Latin America and the rest of the world economy. We also attempt, to the extent possible, to disentangle direct effects stemming from commodity price increases and the indirect effects of the increased influence on traditional trading partners.[10]

13.3 A time-varying weight GVAR model

Whereas most other GVAR applications to date are based on fixed trade weights, the GVAR model developed in this chapter has trade weights allowed to change both at the estimation stage and at the solution stage (when impulse responses are computed). In particular, the GVAR model is estimated with time-varying trade weights, and solved with time-specific trade weights at different points in time. This methodological innovation is important as it allows us to take into account the evidence that trade integration has progressed over time and that the geographical patterns of trade changed dramatically with the acceleration of globalization in the mid-1990s, as documented earlier.

A GVAR model is set up by stacking the estimated individual country-specific models and linking them with a matrix of predetermined cross-country linkages. Having estimated the country-specific parameters using the time-varying weights, the estimated country-specific models can be combined and solved for any given trade weights based either on a particular year or on an average of weights from different time periods.

Several remarks are in order. First, given that we are interested in the impact of changing trade patterns on the transmission of shocks of global relevance, we propose to solve the GVAR (estimated in the first step) for weights or link matrices at different points in time. The GVAR model param-

[10] Other indirect transmission channels, such as financial linkages, are taken into account in the GVAR model through the inclusion financial variables, but they are not discussed separately in the chapter because comparable counterfactual simulation exercises to those used to investigate trade linkages cannot be constructed, given the limited availability of reliable data on bilateral financial positions.

eters are only estimated in the first stage and are taken as given in the second stage. Under the assumption that these parameters are stable over time, the global model can be safely used counterfactually with alternative trade matrices, as we do in our application.

The GVAR model that we specify includes 26 country-specific VARX* models. Data availability limits us to five Latin American economies: Argentina, Brazil, Chile, Peru, and Mexico. The models are estimated over the period 1979q2 to 2009q4, thus including both the great recession of 2008–09 and the first two quarters of the recent global recovery.

With the exception of the US model, all country models include the same set of standard variables—GDP, the inflation rate, the real exchange rate, and, when available, real equity prices, a short interest rate, and a long interest rate. In addition, all country models (except the US) also include the log of nominal oil prices (p_t^o) as a weakly exogenous foreign variable.

The US model is specified differently (see Table 13.3). First, the oil price is included as an endogenous variable. In addition, given the importance of US financial variables in the global economy, the US-specific foreign financial variables are not included in the US model (see below for a discussion of the results of the weak exogeneity test applied to these variables). The real value of the US dollar, by construction, is determined outside the US model, and the US-specific real exchange rate is included in the US model as a weakly exogenous foreign variable.[11]

Table 13.3. Variable specification of the country-specific VARX* models.[a]

Non-US models		US model	
Domestic	Foreign	Domestic	Foreign
y_{it}	y^*_{it}	y_{US}	y^*_{US}
π_{it}	π^*_{it}	π_{US}	π^*_{US}
q_{it}	q^*_{it}	q_{US}	–
ρ^S_{it}	ρ^{S*}_{it}	ρ^S_{US}	ρ^{S*}_{US}
ρ^L_{it}	ρ^{L*}_{it}	ρ^L_{US}	–
–	–	–	$e^*_{US} - p^*_{US}$
$e^*_{it} - p^*_{it}$	p^0	p^0	–

a. In the non-US models, the inclusion of the listed variables depends on data availability.

[11] See Cesa-Bianchi, Pesaran, Rebucci, and Xu (2012) for the country-specific estimates and test statistics of these models.

13.4 Transmission of shocks before and after China's rise in the world economy

To quantify the change in the transmission of external shocks to Latin America before and after the emergence of China as a significant trading nation, we conduct a set of counterfactual simulation exercises along the lines discussed earlier. Specifically, while keeping constant the parameters of the estimated country-specific model, we solve the GVAR model in the second step with four different sets of trade matrices, based on fixed trade weights for the years 1985, 1995, 2005, and 2009. We then compare the resultant time profiles of the transmission of specific GDP shocks across different counterfactual trade linkages.

We consider two country-specific shocks with potential global impacts—namely, a Chinese GDP shock and a US GDP shock—and investigate how their effects on the GDP of selected countries in the GVAR model change using alternative trade matrices. While the Chinese GDP shock is the main focus of our application, we look at a shock to US GDP because it provides a natural benchmark against which to contrast the results for China. We focus on GDP shocks because they are of particular interest in light of the recent global crisis. We also consider a Latin American GDP shock and a GDP shock to the rest of emerging Asia (excluding India) because they shed light on the ongoing debate on the decoupling of emerging markets' business cycles from those of advanced economies. We report some of the point estimates of the GIRFs in the main text (Figures 13.1–13.3). Note that these shocks are not identified, in the sense that they could be triggered by different fundamental sources of disturbances, such as productivity, monetary policy, or other structural shocks, without attempting to identify the ultimate source of the disturbance.[12]

13.4.1 *A Chinese GDP shock*

Figure 13.1 presents the GIRFs for a 1% increase in Chinese GDP, using 2009, 2005, 1995, and 1985 trade weights. In the Latin American region as a whole, the long-run response to this shock with 2009 weights is almost three times as large as the response associated with 1995 weights. The responses of all individual Latin American countries are qualitatively similar, but there are quantitative differences across countries in the region. The long-run responses of Chile and Brazil increase the most (almost four times), while

[12] In principle, traditional impulse responses to orthogonalized shocks could also be computed, but they would depend on the specific identification scheme adopted. For instance, in the case of the typically used Cholesky scheme, the results would depend on the ordering of the variables and countries in the model, while GIRFs are invariant to such orderings.

those of Mexico and Peru increase the least. However, even the changes in the short-run response of Mexican GDP are sizable (reaching almost 0.3% as with the other Latin American countries in 2009), despite the much larger importance of NAFTA trade in Mexico's total trade. This is because a Chinese GDP shock affects both the US and Canada much more strongly with 2009 weights, which generates an indirect effect on Mexico. In contrast, it is puzzling that the strength of the impact and transmission of the shock does not increase in the case of a commodity exporter like Peru, despite the fact that its trade shares have evolved similarly to the other Latin American countries in the sample (see Figure 13.1).

With more recent trade weights (2005 and 2009 weights), a Chinese GDP shock matters much more for both advanced and emerging economies, especially in the long run. For instance, the long-run impact of the shock on the US with 2009 weights is about 50% stronger than with 1995 weights and about 100% stronger than in 1985. For the euro area and Canada, the changes in the transmission of a Chinese GDP shock with 2005 and 2009 weights are even more marked than in the US. The increase in the impact is less pronounced in the case of Japan, but the rest of emerging Asia exhibits the same pattern of progressively increasing responses to a Chinese GDP shock when using more recent weights that the rest of the world displays. Only India, whose trade integration with the rest of the world is mainly driven by trade in services (which is not accounted for in the available trade statistics that we use to compute trade linkages), seems to be affected relatively less by a Chinese GDP shock with more recent trade weights. Moreover, differences between 2009 and 1985 responses to a Chinese GDP shock are not only quantitatively sizable but also statistically significant in the sense that in most cases, the 95% error bands for the bootstrapped 2009 responses do not contain zero values.

The reported changes in the transmission of the Chinese GDP shock to Latin America and the rest of the world are likely to have played an important role in the unfolding of the recent global financial and economic crisis. For instance, Cova, Pisani, and Rebucci (2010) estimate that, absent the large fiscal stimulus enacted by China during the global crisis, China's GDP would be 2.6 percentage points lower in 2009. The estimated elasticities to a Chinese GDP change reported in Figure 13.1 imply that US GDP growth would have been a quarter percentage point lower in 2009, and Latin American GDP growth would have been almost a full percentage point lower.[13] Conversely, suppose that Chinese growth slowed in the medium-to-long term to about 7% a year, as currently forecasted in China's twelfth

[13] With 2009 trade weights, the peak impacts of a Chinese GDP shock on US GDP and Latin American GDP are 0.12% and 0.3%, respectively.

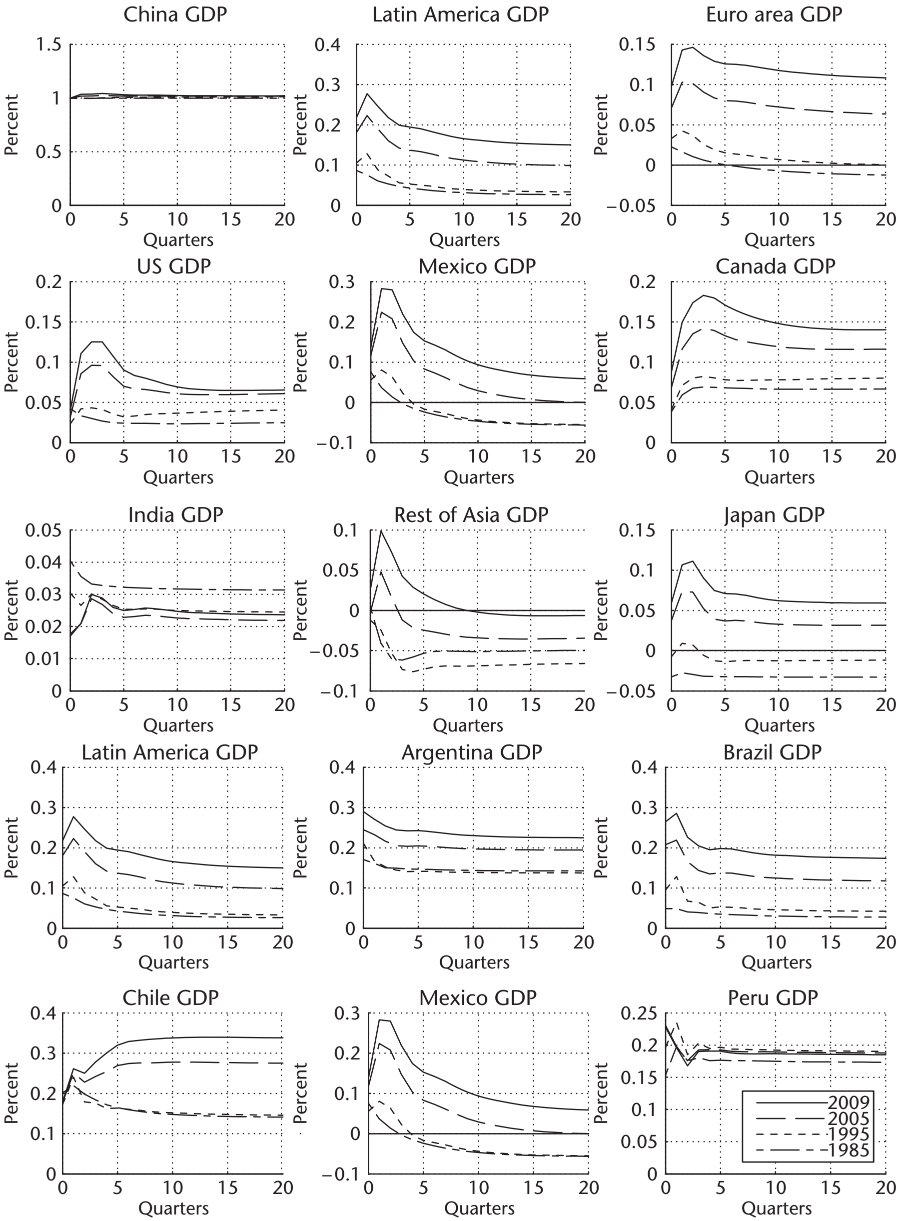

Figure 13.1. GIRFs for a 1% increase in Chinese GDP.

Notes: Point estimates for 1985, 1995, 2005, and 2009.

official five-year plan. This would shave almost half a percentage point from Latin America's long-term growth—probably more than 10% of the region's growth potential—with much larger short-term effects.[14] These effects are quite sizable, especially considering that these back-of-the-envelope calculations do not account for any likely associated financial market overreaction to such important changes in the fundamental driver of the region's business cycle.

In light of Mexico's responses to a Chinese GDP shock and, more generally, the stylized facts discussed in earlier sections, we questioned whether the increased impact of a Chinese GDP shock on other Latin American countries is due to direct or indirect trade linkages. That is, we set out to quantify whether the stronger impact of China on Latin America is more due to stronger bilateral trade ties between China and the region or to stronger indirect effects emanating from China's impact on the region's traditional and largest trading partners, namely, the US and the euro area. To separate out these two effects, we conducted an additional counterfactual simulation, taking the 2009 trade matrix and changing China's weights in the total trade of the Latin American economies, with the exception of Mexico, to 1995 levels (thus resetting the direct trade links between the region and China to the 1995 level). All other entries in the link matrix were initially kept at their 2009 values, thus leaving the indirect links via the US and the euro area unchanged. The difference between China's 1995 and 2009 weights in the total trade of each of the four Latin American countries was then redistributed proportionally to the remaining countries, excluding the US and the euro area, which were left unchanged at their 2009 levels. In this experiment, we also left Mexico's direct trade link with China unchanged at its 2009 level, because otherwise the response of the US to the Chinese GDP shock with this hybrid link matrix would change due to Mexico's large trade share in US total trade, and the exercise would overstate the effects on Mexico.[15]

The results are reported in Figure 13.2 and show that the indirect linkages are likely to be more important than the direct linkages, thus highlighting the strength of the general equilibrium dynamics that the GVAR modelling strategy captures. Muting the change in the direct trade link between China and Latin America (excluding Mexico) has no consequences on the US, the

[14] We conduct the following calculations: if China's growth rate falls by 3 percentage points to 7% a year, and given an estimated long-run elasticity of a Chinese GDP shock on Latin American GDP of about 0.15, the contraction implies a fall in Latin American GDP growth of around 0.4–0.5 percentage points in the long run. Assuming that Latin America's long-run growth rate is between 4% and 5% a year (as in the case of Brazil), a reduction of GDP growth by 0.4–0.5 percentage points represents a decline in potential growth of approximately 10%.

[15] In fact, Mexico had a 14% share of total trade of the US in 2009, according to the IMF's Direction of Trade Statistics.

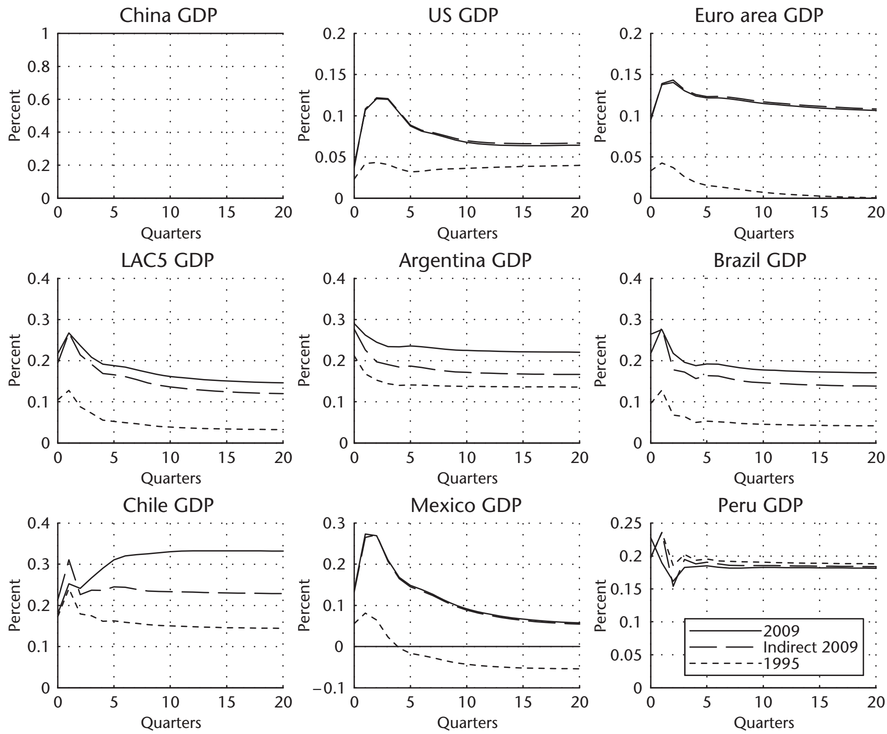

Figure 13.2. GIRFs for a 1% increase in Chinese GDP: total and indirect effects.
Notes: Point estimates for 2009 and 1995; indirect effects for 2009.

euro area, or Mexico itself by construction. This is because Latin America excluding Mexico (whose trade shares are kept constant) is too small in trade terms to affect the US. In the cases of Argentina, Brazil, and Chile, the changes in the impact of the Chinese GDP shock due to changed indirect linkages are at least as large as those due to changes in the direct links: changed indirect linkages explain at least half of the total change in the transmission of the shock (almost all of the change in the case of Brazil). In the case of Peru, there is a very small total change, so the distinction is immaterial. We interpret this evidence as suggesting that both direct and indirect effects contribute to the stronger impact of a Chinese GDP shock on the four Latin American countries, but the indirect transmission channel is at least as important as the more obvious direct links. In some cases, such as Brazil, the indirect effects seem to be even more important than the direct effects.

This is clear evidence that the changed trade linkages between China, Latin America, and the rest of the world are affecting the region not only via stronger direct trade linkages (boosted by a persistent increase in commodity prices, which inflates the Latin American trade shares), but also through stronger ties between China and the region's traditional trading partners. An important implication of this result is that other countries in the broader Latin American region, such as countries in Central America and the Caribbean, might now be more affected by China via the increased impact of a Chinese GDP shock on the US and the euro area. This result also suggests that the increased impact of a Chinese GDP shock on Mexico discussed above can be interpreted as a result of stronger indirect trade linkages between China and the other NAFTA member countries.

13.4.2 *A US GDP shock*

Figure 13.3 presents the GIRFs for a 1% increase in US GDP. The impact of a US GDP shock on advanced and emerging market economies falls considerably with more recent trade weights, especially in the short term, mirroring the shift in the geographical distribution of trade discussed earlier. Specifically, the impact of the shock on the US itself with 2009 weights is almost half the size with 1995 weights in the first few quarters, and it is about 20–25% weaker over the longer term. The results for Canada are similar. In the case of the euro area, the transmission of the shock weakens more uniformly across the horizon of the GIRF.

In the case of Latin America, the short-term impact of this shock falls dramatically with 2009 weights (becoming statistically insignificant), while the long-run impact is half that using 1995 weights. As in the case of the Chinese GDP shock, there are quantitative differences in responses of individual Latin American countries, but the qualitative pattern is common across all five economies. The long-run responses of Chile decrease the most, by almost half compared with 1995 trade weights. The reduction in the response is smallest for Mexico, though it is still sizable; this is to be expected given Mexico's membership in NAFTA.

The changes in the impact of the US GDP shock on Asia are more mixed. The long-run impact on Chinese GDP falls dramatically with 2009 weights compared with the estimates using 1985 weights. However, these differences are significant only for the first two quarters. Japan and the rest of emerging Asia (driven by Korea, which is not reported separately) show some differences in the short-run effects, but the evidence does not imply a reduction in the impact of a US GDP shock on these economies in the long run. Moreover, the bootstrapped responses show that these changes are not statistically significant.

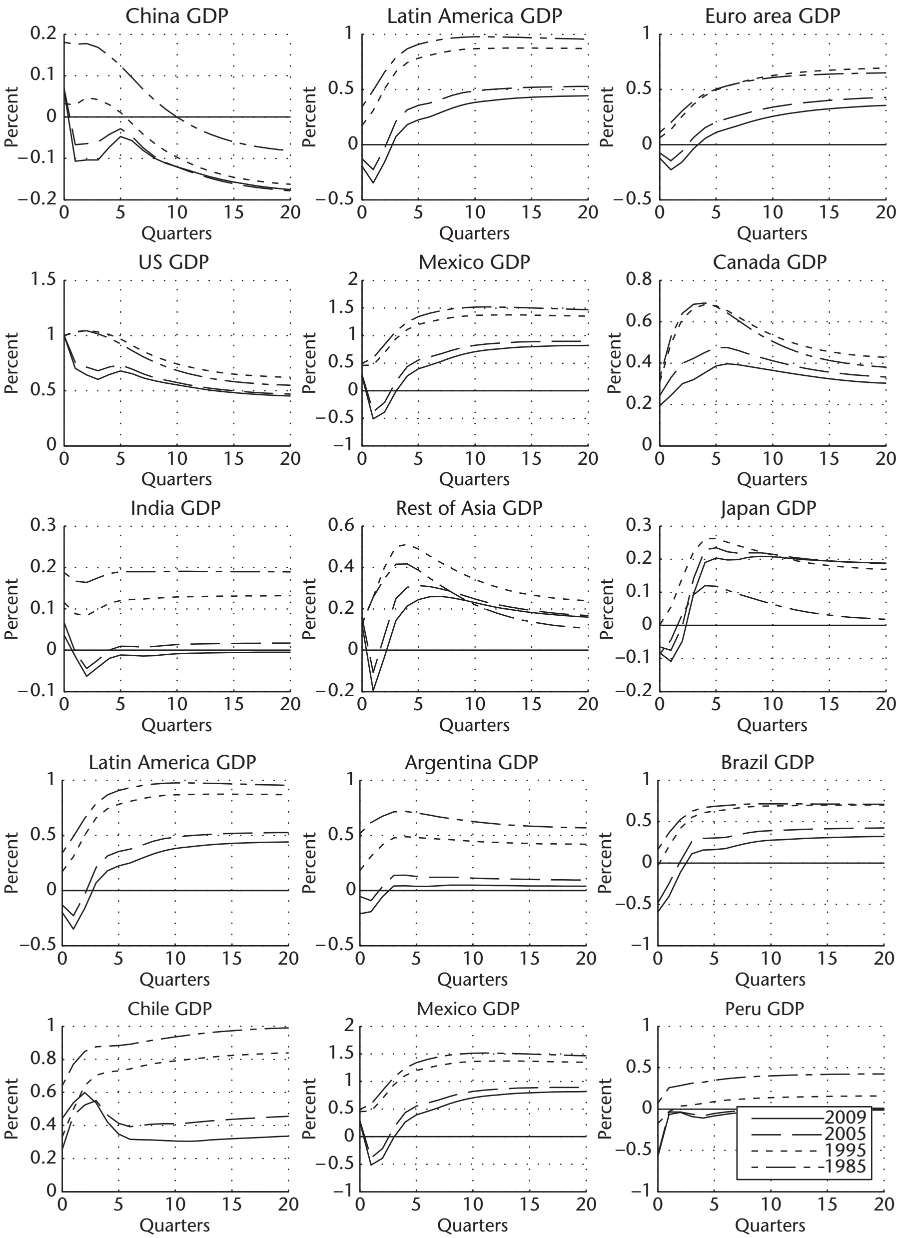

Figure 13.3. GIRFs for a 1% increase in US GDP.

Notes: Point estimates for 1985, 1995, 2005, and 2009.

These results imply that the effect of the recent US great recession on Latin America would have been much more severe if this event had taken place in the mid-1990s. For instance, Izquierdo and Talvi (2011) estimate that the level of US GDP at the peak of the recession was more than 7% below its potential. If the crisis had taken place in the mid-1990s, rather than the late 2000s, our simulations show that Latin America could have experienced the same output gap as the US based on these estimates.[16] While good initial conditions at the beginning of the crisis and prompt international financial support have helped the region cope well with the recent global crisis, less dependency on the country at the epicentre of the crisis (the US) has proved to be fortunate for the economic performance of the region.

13.4.3 *A GDP shock in Latin America and the rest of emerging Asia*

Our model also speaks to the much-debated decoupling hypothesis. According to this hypothesis, emerging markets have decoupled from advanced economies in recent years, in the sense that their growth dynamics have become more autonomous.[17] As a result, emerging markets as a group are starting to be an autonomous source of world growth.

To test this hypothesis, we consider a 1% increase in Latin American GDP and in the GDP of emerging Asia (excluding China and India).[18] These shocks are constructed as the weighted average (PPP-GDP average) of shocks to GDP in all Latin American and emerging Asian countries in the model, respectively. The effects of these shocks with 2009 trade weights have remained virtually unchanged in the case of Latin America, and they have weakened slightly in the case of the emerging Asian economies. These results, taken together with those on the transmission of a Chinese GDP shock, show that Latin America and the rest of emerging Asia are still too small to have a meaningful impact on the world economy. They cannot, as yet, be counted as an autonomous source of world growth, like China.

Our findings also suggest that Latin America and the rest of emerging Asia remain a collection of small, open economies whose fluctuations can be affected strongly by the international business cycle. The key change we document is that their cycle is now more exposed to China and less exposed to the US than in the past (although the impact of a US GDP shock remains sizable). This impact occurs not only directly via stronger bilateral trade ties, but also, and perhaps more importantly, indirectly via China's stronger ties with advanced economies. In other words, the evidence reported in this

[16] The long-run impact of a positive shock of a 1% rise in US GDP on Latin American output is about 1% with 1995 weights, but only about 0.4% with 2009 weights.

[17] See Kose and Prasad (2010) for an example of the decoupling hypothesis.

[18] We do not report the impulse responses here for sake of brevity.

chapter suggests that the decoupling of emerging markets from advanced economies found in the existing literature is more likely related to the emergence of China as an important source of world growth, as opposed to a widespread decoupling of emerging market business cycles from cycles in advanced economies.

13.5 Conclusions

In this chapter we investigated how China's emergence in the world economy has affected the international transmission of business cycles to five large Latin American economies. We found that the long-run impact of a Chinese GDP shock on the typical Latin American economy has increased three times since the mid-1990s. In contrast, the long-run effect of a US GDP shock has halved over the same period, with even sharper declines in the short-term impact. We show that the larger impacts of a Chinese GDP shock owe as much to indirect effects, associated with stronger trade linkages between China and Latin America's largest trading partners (namely, the US and the euro area) as to direct effects stemming from tighter trade linkages between China and Latin America, boosted by the decade-long boom in commodity prices that has inflated trade shares. The results also suggest that the transmission of domestic shocks originating in Latin America and the rest of emerging Asia (excluding China and India) has not changed much over the same period.

These findings help to explain why the five Latin American economies we consider recovered much faster than initially anticipated from the recent global crisis. In fact, the evidence shows that Latin America's growth was mostly driven by a fast-growing economy that enacted a powerful fiscal stimulus during the global crisis, with a relatively smaller pull from the economy that was at the epicentre of the crisis. Had the trade linkages been those prevailing in the mid-1990s, the region would have likely suffered a much sharper downturn than it actually experienced.

These same findings expose new vulnerabilities for Latin America and the rest of the world economy. Latin America and the rest of the world economy, including the region's traditional and still largest trading partners, now rely relatively more on China and less on the US relative to only 15 years ago. China is a large, low-middle-income economy whose transition to high-income economy will continue for many years to come. China is also relatively less stable than the US. While the changes documented here have had positive, stabilizing effects on the Latin America business cycle during the recent global crisis, the same facts may predict negative, destabilizing effects if and when China's growth begins to slow. Thus, going forward, Latin America and the rest of the world are likely to become more volatile.

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14

Does one size fit all? Modelling macroeconomic linkages in the West African Economic and Monetary Union

David Fielding, Kevin Lee, and Kalvinder Shields

14.1 Introduction

Fully structural macroeconomic models are relatively rare in development economics because there are few countries in which quarterly macroeconomic data are recorded over a long enough period for such modelling to be feasible and because the traditional, large-scale simultaneous equation approach to macroeconometric modelling simply asks too much of the data that is available. Fielding, Lee, and Shields (2012) construct a structural macroeconometric model for the member states of the West African Economic and Monetary Union (UEMOA) and show that data limitations can be overcome using the GVAR modelling framework.

Modelling difficulties arising in this context are addressed by four means: by the careful construction of 'foreign' variables for each country to measure outside influences and to capture within-union and cross-border interactions parsimoniously;[1] by a pragmatic use of data available at annual and quarterly frequencies to fully exploit all the available information; by adopting the long-run structural modelling strategy proposed in Garratt et al. (2003, 2006) to ensure the model has a coherent long-run economic structure; and by organizing the work within the GVAR modelling framework to capture

[1] Sometimes, outside 'global' variables are constructed for purely pragmatic reasons to simplify the statistical structure of national relationships. On other occasions, global variables are economically meaningful in their own right. As we shall see, the UEMOA model illustrates both these features, incorporating union-wide relationships that contain meaningful aggregates and national relationships that contain aggregated variables as convenient simplifications.

in a single, unified system the complexities of the relationships that exist within and between the nations of the union. These methods allow a model of the economies of UEMOA to be constructed that incorporates meaningful steady-state relationships within and across the member states of the union but allows the short-run dynamic properties of the model to be driven by the data. The GVAR model incorporates the channels through which macroeconomic innovations in one country impact on other countries in the union and reveals the extent of heterogeneity that exists in the macroeconomic transmission mechanisms across member states. This is important because this heterogeneity constitutes a significant element in measuring the costs of union membership for each country.

The value of constructing structural macromodels of developing economies, both individually and as they interact with each other, is well illustrated by the UEMOA member states. Over the past 40 years most economies in Sub-Saharan Africa have been characterized by exchange rate instability, financial fragility, and high inflation. The continent as a whole is the furthest from achieving the UNDP's Millennium Development Goals, and seems to be diverging from, rather than converging to the industrialized world (Easterly and Levine, 1997; World Bank, 2003). Many Sub-Saharan African countries are economically very small, and it is possible that one factor inhibiting African economic development is the absence of opportunities to exploit economies of scale in production and trade. Monetary union provides one possible route to greater macroeconomic integration and it is interesting to investigate its costs and benefits through structural modelling. The West African Economic and Monetary Union (UEMOA) provides a good case study. In this, eight countries have a single currency and a single central bank setting its own interest rate and credit creation targets. The central bank (the BCEAO) dates from 1955, seven years before the end of French rule, and most of the current member states have never had a national currency. At the outset of the union, the currency was pegged at a fixed rate against the French franc and now it is pegged against the euro. There was a single devaluation of the currency against the French franc in January 1994.

There is evidence suggesting that membership of a monetary union has generated substantial benefits for many of the UEMOA member states in terms of monetary and financial stability and regional integration (Stasavage, 1997; Fielding and Shields, 2005). However, as is well known from optimum currency area theory, there are also potential costs. If the countries experience heterogeneous macroeconomic shocks, the imposition of a single monetary policy will result in welfare losses relative to a world in which all countries have their own currency. Equally, if shocks (or indeed monetary policy responses) are transmitted in different ways in different countries, a single currency entails some cost. Identifying the structural linkages between the countries of a monetary union is essential in understanding the macroeconomic consequences of a single currency. While there are a few existing papers on macroeconomic shocks in the union (Hoffmaister et al., 1998; Fielding and Shields, 2001; Fielding et al., 2004), these papers are based on VAR models containing just two or three aggregate variables with a limited identification structure; they are not designed to identify the structural linkages between member states.

The GVAR model of the UEMOA provides a structural model of the sort necessary to investigate the detail of how the different countries' economies within the union are interrelated in order to inform monetary policy within the region. In what follows in Section 14.2, we briefly outline the theoretical framework describing the relationships between macroeconomic aggregates within each country and the linkages between countries in the UEMOA. The framework focuses on the relationships that are likely to hold in the long run for which there is a degree of consensus amongst economists and provides a coherent and economically meaningful structure around which the UEMOA model is formed. Section 14.3 then explains how this framework is translated into a GVAR set-up applying the 'long-run structural' modelling strategy in which the long-run relationships that exist within and across countries are embedded within an otherwise unrestricted VAR model. The use of the GVAR modelling framework then captures the complicated dynamics that exist in the data without imposing a contentious identifying structure on the short-run relationships. Section 14.4 describes the data and the estimated model for the UEMOA, and provides some insights on the dynamic properties of the model of UEMOA through an impulse response analysis. Section 14.5 concludes.

14.2 The theory-based long-run relationships

The 'long-run structural' modelling strategy described by Fielding et al. (2012) is used where, in the first stage of the analysis, economic theory is used to motivate the structural relationships that exist within countries of the UEMOA over the long run:

1. The UEMOA is a common currency area, so there is a single demand curve for (narrow) money across the union. A positive shock to the nominal money stock is likely to generate inflation in all countries, although in the short run the extent of this inflation may vary because of differences in the extent of price stickiness across countries.
2. In the long run, the mobility of goods and factors within the monetary union is likely to guarantee at least weak purchasing power parity across

all the countries. Strong PPP might not hold because of heterogeneity in the local prices of non-traded goods, caused by differences in local supply and demand conditions.

3. Until recently there were no effective constraints on individual governments' borrowing from the BCEAO, but the BCEAO faces a binding external financing constraint in the form of the operations account. So in our data (ending in 2000), any binding long-run balance of payments condition is likely to apply to the UEMOA as a whole, rather than to individual countries. When there is a shock to the trade balance of one country, through an innovation in its terms of trade for instance, adjustment of prices and output to maintain a long-run external balance is likely to be spread across all the members of the union.
4. The levels of aggregate demand in each country are likely to be linked in several ways. First, all the countries face common interest rates. Second, each country's price level, and therefore its real exchange rate, is likely to depend on events in other countries for the reasons outlined in (1)–(3) above. Third, there is substantial labour mobility across the countries of the UEMOA, especially immigration into Côte d'Ivoire from its smaller neighbours, with correspondingly large remittances out of Côte d'Ivoire. This means that shocks to income in one economy, particularly in Côte d'Ivoire, are likely to have a direct impact on aggregate demand in at least some of the others.

In view of points (1)–(4) above, the long-run structural relationships include: (i) an aggregate LM curve for the whole monetary union; (ii) an aggregate BP curve for the whole monetary union; (iii) $n-1$ PPP equations linking prices in each of the n countries of the union; and (iv) n IS curves, one for each country, describing the determination of country-specific aggregate demand.[2] The interactions between economies are therefore accommodated partly through the use of zone-wide relationships in (i) and (ii), and partly through the use of aggregate, zone-wide variables constructed on the basis of the corresponding variables measured at the level of the individual economies.

More formally, the long-run structural model involves $4n+4$ distinct variables. There are four variables that exist only at the union-wide level: the UEMOA Franc—French Franc exchange rate, S_t; the total money base issued in the countries, M_t; a common nominal interest rate faced by all countries, R_t; and a measure of world activity, Y_t^g. The remaining $4n$ distinct variables consist of four variables measured for each country: real GDP in country

[2] There are no explicit aggregate supply relationships in the model. However, the model is consistent with the existence of country-specific productivity shocks that impact on the country's output and on all other variables in the system through the relations embedded in the model.

i, Y_{it} $(i = 1, \ldots, n)$; the consumer price index, P_{it}, and the export price, P^{x}_{it}, reflecting the price in UEMOA francs of goods produced in country i $(i = 1, \ldots, n)$, and consumed in country i or exported abroad; and the import price index, P^{z}_{it}, reflecting the price in French francs of goods produced abroad but imported to country i $(i = 1, \ldots, n)$. In the work, we also make use of import volumes in each country i, Z_{it} $(i = 1, \ldots, n)$. Using lower case letters to denote logarithms, so that $y_{it} = \log(Y_{it})$ and so on, the union-wide variables corresponding to the economy-wide variables are defined by their weighted geometric averages and are identified by the star-superscript throughout. Hence, union-wide output level is $y^{*}_{t} = \sum_i w^{y}_{i} y_{it}$; the union-wide price level is $p^{*}_{t} = \sum_i w^{y}_{i} p_{it}$, the union-wide export price is $p^{x*}_{t} = \sum_i w^{z}_{i} p^{x}_{it}$, and the union-wide import price is $p^{z*}_{t} = \sum_i w^{z}_{i} p^{z}_{it}$. The country weights $\mathbf{w}^{y} = (w^{y}_{1}, .., w^{y}_{n})'$ are based on the relative size of the country by output over the sample period (so that $w^{y}_{i} = \sum_t y_{it} / \sum_i \sum_t y_{it}$), while the $\mathbf{w}^{z} = (w^{z}_{1}, \ldots, w^{z}_{n})'$ are based on the relative size of the country by import activity (so that $w^{z}_{i} = \sum_t z_{it} / \sum_i \sum_t z_{it}$).

Using these definitions, and based on the economic relationships described in (i)–(iv) above, the model contains $2n + 1$ long-run relations of the form:

$$m_t - p^{*}_{t} = a_0(t) + a_1 y^{*}_{t} - a_2 R_t - a_3 \Delta p^{*}_{t} + a_4 s_t + \xi_{at}, \tag{14.1}$$

$$e^{*}_{t} = b_0(t) + b_1 y^{*}_{t} + b_2 \left(p^{*}_{t} - p^{x*}_{t}\right) + b_3 y^{g}_{t} + b_4 s_t + \xi_{bt} \tag{14.2}$$

$$p_{it} = c_{i0}(t) + p^{*}_{t} + c_{i1} s_t + \xi_{cit}, \qquad i = 1, ..., n-1, \tag{14.3}$$

and

$$y_{it} = d_{i0}(t) + d_{i1} e_{it} - d_{i2} \left(R_t - \Delta p_{it}\right) + d_{i3} y^{g}_{t} + \xi_{dit} \qquad i = 1, ..., n, \tag{14.4}$$

where $e_{it} = s_t + p^{z}_{it} - p_{it}$ are the national real exchange rates and $e^{*}_{t} = s_t + \sum_i w^{z}_{i} \left(p^{z}_{it} - p_{it}\right)$ is the aggregate union-wide analogue. If we take R_t, s_t, y^{g}_{t}, p^{x}_{it} and p^{z}_{it} as exogenous, then there are $2n + 1$ equations in (14.1)–(14.4) explaining the long-run determination of $2n + 1$ endogenous variables; namely m_t, the y_{it} $(i = 1, \ldots, n)$, and the p_{it} $(i = 1, \ldots, n)$. Hence, the system is exactly identified in the long run.

Equation (14.1) describes the long-run LM curve for the whole monetary union, with the demand for real money balances influenced by zone-wide activity and interest rates. Equation (14.2) reflects the binding balance-of-payments condition faced at the union level, with the aggregate real exchange rate adjusting in the face of union-level activity, terms of trade, and world trade. The $n - 1$ relations of (14.3) reflect the weak purchasing power parity that will hold across the nations in the long run. In all of these cases, we allow for the possibility that the devaluation had a permanent impact on the relations through the inclusion of s_t as a separate variable in the first three equations. (This is effectively a dummy variable, as the exchange rate changed only once in the sample period.) Finally, the n relations of (14.4) describe product market equilibrium in each of the individual nations, with aggregate demand influenced by the country-specific real exchange rate, real interest rates (defined with reference to the country's own inflation rate), and levels of world trade.[3]

Identification of the deterministic components of the equations in (14.1)–(14.4), i.e. $a_0(t)$, $b_0(t)$, etc., will be based on empirical information criteria. We expect all other parameters to be positive. The terms ξ_{at}, ξ_{bt}, $\boldsymbol{\xi}_{ct} = (\xi_{c1t}, \ldots, \xi_{c,n-1,t})'$, and $\boldsymbol{\xi}_{dt} = (\xi_{d1t}, \ldots, \xi_{dnt})'$ are $2n + 1$ stationary errors, which represent deviations from equilibria in each of the long-run relations. The errors may have substantial serial correlation, indicating that disequilibria may last for protracted periods in different markets. But the fact that they are stationary reflects the view that the disequilibria will vanish in the long run.

14.3 Organizing the theoretical relationships within a GVAR framework

The theoretical model described above concentrates on the long-run relationships that exist among the macroeconomic variables of a country and between the various countries of UEMOA. Embedding these long-run relationships within a VAR framework allows the capture of the complicated short-run dynamic relations between the countries' variables; for details, see Garratt et al. (2003, 2006). In doing so, the short-run and long-run relationships that exist within and across the union member states are accommodated in a single unified GVAR system.

The GVAR model is constructed by stacking together the $4n + 4$ distinct variables of interest in a single vector of variables, $\mathbf{z}_t$, where

$$\mathbf{z}_t = (R_t,\ s_t,\ y_t^g,\ \mathbf{p}_t^{x\prime},\ \mathbf{p}_t^{z\prime},\ m_t,\ \mathbf{y}_t',\ \mathbf{p}_t')',$$

and $\mathbf{p}_t^z = (p_{1t}^z, \ldots, p_{nt}^z)'$, $\mathbf{p}_t^x = (p_{1t}^x, \ldots, p_{nt}^x)'$, $\mathbf{y}_t = (y_{1t}, \ldots, y_{nt})'$ and $\mathbf{p}_t = (p_{1t}, .., p_{nt})'$. Next the vector of long-run structural disturbances $\boldsymbol{\xi}_t = (\xi_{at}, \xi_{bt}, \boldsymbol{\xi}_{ct}', \boldsymbol{\xi}_{dt}')'$, containing the disequilibria from the long-run relations in (14.1)–(14.4) is written as a linear combination of the variables in $\mathbf{z}_t$:

$$\boldsymbol{\xi}_t = \boldsymbol{\beta}'\mathbf{z}_t - \mathbf{b}(t) - \boldsymbol{\delta}\Delta\mathbf{z}_t \tag{14.5}$$

[3] The justification for the use of a common interest rate in the countries' IS relations is provided below.

for an appropriate deterministic vector $\mathbf{b}(t)$ and with $\boldsymbol{\beta}'$ and $\boldsymbol{\delta}$ both being $(2n+1)\times(4n+4)$ matrices of the form

$$\boldsymbol{\beta}' = \begin{pmatrix} a_2 & 0 & 0 & \mathbf{0} & \mathbf{0} & 1 & -a_1\mathbf{w}^{y\prime} & -\mathbf{w}^{y\prime} \\ 0 & 1 & -b_3 & b_2\mathbf{w}^{z\prime} & \mathbf{w}^{z\prime} & 0 & -b_1\mathbf{w}^{y\prime} & -\left(1+b_2\right)\mathbf{w}^{z\prime} \\ \mathbf{0} & \mathbf{0} & 0 & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \Theta_1' \\ \mathbf{d}_2 & -\mathbf{d}_1 & -\mathbf{d}_3 & \mathbf{0} & -\mathbf{d}_1\mathbf{w}^{z\prime} & \mathbf{0} & \mathbf{I}_n & \mathbf{d}_1\mathbf{w}^{z\prime} \end{pmatrix} \tag{14.6}$$

and

$$\boldsymbol{\delta} = \begin{pmatrix} 0 & 0 & 0 & \mathbf{0} & \mathbf{0} & 0 & \mathbf{0} & a_3\mathbf{w}^{y} \\ 0 & 0 & 0 & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & -\mathbf{d}_2\mathbf{w}^{y\prime} \end{pmatrix},$$

where Θ_1 is the first $n-1$ rows of $\mathbf{w}-\mathbf{w}^y$, where $\mathbf{w}$ is an n-vector of ones, where $\mathbf{d}_1$, $\mathbf{d}_2$, and $\mathbf{d}_3$ are n-vectors containing the parameters d_{i1}, d_{i2} and d_{i3}, $i=1,\ldots,n$, respectively. The final step in the long-run structural modelling strategy is to embed the structural disturbances, $\boldsymbol{\xi}_{t-1}$, in a VAR($s-1$) model in $\Delta\mathbf{z}_t$:

$$\Delta\mathbf{z}_t = \overline{\mathbf{a}}(t) - \boldsymbol{\alpha}\boldsymbol{\xi}_{t-1} + \sum_{i=1}^{s-1}\overline{\Gamma}_i\Delta\mathbf{z}_{t-i} + \mathbf{v}_t, \tag{14.7}$$

where, given the assumption that R_t, s_t, y_t^g, p_{it}^x and p_{it}^z are determined exogenously, $\boldsymbol{\alpha}$ will be of the form $\boldsymbol{\alpha} = (\boldsymbol{\alpha}_{ex}', \boldsymbol{\alpha}_{en}')'$ with $\boldsymbol{\alpha}_{ex}$ a $(2n+3)\times(2n+1)$ matrix of zeros. In view of (14.5), (14.7) can be written equivalently as

$$\Delta\mathbf{z}_t = \mathbf{a}(t) - \boldsymbol{\alpha}\boldsymbol{\beta}'\mathbf{z}_{t-1} + \sum_{i=1}^{s-1}\Gamma_i\Delta\mathbf{z}_{t-i} + \mathbf{v}_t, \tag{14.8}$$

where $\mathbf{a}(t) = \overline{\mathbf{a}}(t) - \boldsymbol{\alpha}\mathbf{b}(t)$, $\boldsymbol{\Gamma}_1 = \overline{\boldsymbol{\Gamma}}_1 - \boldsymbol{\alpha}\boldsymbol{\delta}\Delta\mathbf{z_t}$, $\boldsymbol{\Gamma}_i = \overline{\boldsymbol{\Gamma}}_i$, $i=2,\ldots,s-1$. This is, of course, the familiar vector error-correction (VECM) form. The form of the model allows for the presence of complex dynamic relationships between the variables of the system but accommodates also the long-run relationships that exist between the levels of the variables in influencing these dynamics.

Having unpacked the starred variables into their constituent national parts in defining $\mathbf{z}_t$, the model in (14.8) now describes the structural relations between all the variables measured at the national and union-wide levels in a single unified system: hence the term 'global VAR'.

14.4 The GVAR model of UEMOA

Developing the GVAR model of the UEMOA empirically is not entirely straightforward (see also, Fielding et al., 2012 for details). For example, the shortage of quarterly national accounts data means that there are no official GDP statistics reported on a quarterly basis and quarterly series have to be interpolated from the annual GDP data using quarterly figures for electricity consumption. In practice, this is possible for only five of the eight members of the UEMOA; namely, Burkina Faso, Mali, Senegal, Togo, and Côte d'Ivoire, although the model still captures the main features of the union, given that these five countries make up over 90% of the GDP of the UEMOA. Similarly, the only UEMOA interest rate reported consistently for any length of time is the BCEAO rediscount rate, which changes seldom. Consequently, the nominal interest rate R_t is defined as the French government bond yield, implicitly assuming a substantial degree of capital market integration between the UEMOA and France. The fact that, in the long run, there appears to be interest parity even with respect to the very sticky BCEAO rediscount rate suggests that this is a reasonable assumption.

Perhaps most importantly, quarterly GDP figures are not available for years prior to 1987. In order to abstract from any structural changes that may have taken place when France adopted the euro, the model is estimated up to 2000. This is therefore a rather short time period on which to estimate the long-run restrictions in equations (14.1)–(14.4). Annual data are available for a longer time period (1970–2000), however, so the model is estimated using both annual and quarterly data in a two-step procedure. In the first step, the long-run relations in equations (14.1)–(14.4) are estimated using the annual data and single-equation estimation techniques. The estimated long-run relations are then used to construct corresponding disequilibrium measures at the quarterly frequency and, in the second step, these disequilibrium terms are included in the estimation of a structural model of the form in (14.8) using the quarterly data. The estimation of the model in two stages represents a pragmatic procedure to overcome the modelling difficulties arising from the limitations of the data and to best exploit the data that is available.

14.4.1 *The estimated long-run relationships*

The single-equation estimation method of Pesaran, Smith, and Shin (2001) [PSS] is adopted to estimate the long-run relationships in (14.1)–(14.4) separately using annual data. This method does not require knowledge of the order of integration of the series under consideration (although all of the variables involved are assumed either $I(0)$ or $I(1)$). Taking each of the

Table 14.1. Bounds test.

	Dependent variable										
	$\Delta(m_t - p_t^*)$	Δe_t^*	Δp_{1t}	Δp_{2t}	Δp_{3t}	Δp_{4t}	Δy_{1t}	Δy_{2t}	Δy_{3t}	Δy_{4t}	Δy_{5t}
F_{BOUNDS}	6.44	4.53	5.24	6.16	6.18	5.25	4.53	4.54	3.61	8.81	7.57

Notes: The table gives the F-statistics testing the joint insignificance of the lagged level terms.

relationships in (14.1)–(14.4) in turn, this method involves treating the left-hand-side variable as a dependent variable and regressing its difference on the contemporaneous differences of the other variables involved, on up to s lags of its own difference and the differences of the other variables, and on the first lag of the levels of all the variables involved. It is assumed that there exists only one long-run relationship among the variables under consideration (as is the case here, when each of the relationships in (14.1)–(14.4) are considered in turn).

The regressions provide good evidence of the existence in the data of the long-run equilibrium relationships suggested in (14.1)–(14.4).[4] The Table 14.1 summarizes the F-statistics testing the joint insignificance of the lagged levels terms in each of the 11 relationships, where the subscripts 1 to 5 refer to Burkina Faso, Mali, Senegal, Togo, and Côte d'Ivoire, respectively. The F_{BOUNDS} test statistic in all cases lies above the corresponding upper bound critical value, provided in PSS, indicating that the null hypothesis (that there is no long-run relationship among the levels series) is rejected.

The estimated long-run income elasticity of money demand is 2.48, while the long-run interest elasticity is -1.41. These values are larger than the income and interest elasticities of demand for narrow money estimated in some other African countries (see, for example, Adam, 1992), but they are consistent with standard economic theory. In the BP relationship (see equation (14.2)), the coefficients on y_t^*, $(p_t^* - p_t^{x*})$ and y_t^g are equal to 1.14, 0.06, and -0.01, respectively, which are in line with theory. The estimated exchange rate pass-through to domestic prices is equal to 62.2% of the devaluation of the nominal exchange rate in 1994 passed through into domestic prices. The devaluation dummy shows significant effects in all four of the national price relationships of (14.3) also. These reflect the percentage increase or decrease in equilibrium prices in the country relative to the UEMOA average following the devaluation, confirming that the impact of the devaluation on domestic prices varied across the monetary union. The PPP assumption was kept despite some weak evidence against it. Finally, the estimated IS curves (see equation (14.4)) were found to be downward-

[4] See Fielding et al. (2012) for full details of the estimated ARDL models corresponding to the $2n + 1 = 11$ relationships in (14.1)–(14.4) using the annual data available over 1972–2000 for Burkina Faso, Mali, Senegal, Togo, and Côte d'Ivoire.

sloping, although by differing degrees across countries. In most cases, there is also a positive relationship between y_{it} and e_{it}, and between y_{it} and y_t^g so that greater price competitiveness and increasing world trade boosts aggregate demand, although again there was variation in the long-run elasticities across countries.

14.4.2 *The VECM regressions*

In the second stage of the estimation procedure, the information gleaned from the ARDL models estimated using the relatively long sample of annual data was incorporated into a GVAR model of the form of (14.8) and estimated using quarterly data. This allows the consideration of the dynamic properties of the system as a whole, investigating the extent to which shocks in one part of the monetary union are transmitted elsewhere and how much heterogeneity there is in the transmission mechanisms of the different economies.

For each of the endogenously determined variables (namely, m_t, p_{it}, $i = 1, \ldots, 5$, and y_{it}, $i = 1, \ldots, 5$), the estimated error-correction specifications include the first lag of the disequilibrium terms defined in the ARDL analysis, up to four lags of the differences of the endogenous variables and the (current and lagged) difference of the exogenous variables. The resulting equations accommodate complicated dynamics with strong and significant feedbacks in most equations from the union-wide LM and BP disequilibria, the individual country's IS disequilibrium, and all of the separate countries' PPP disequilibria (reflecting the idea that there is the potential for arbitrage across each pair of countries).[5] The estimated VECM regressions therefore provide a comprehensive description of the dynamics of the 11 endogenous and eight exogenous variables under investigation, automatically incorporating the long-run structure suggested by theory through the inclusion of the disequilibrium terms. Subsequent recasting of the model into the unified GVAR system in (14.8) through the unpacking of the 'starred' union-wide variables into the weighted sum of their national counterparts allows the system properties to be properly investigated.

14.5 The dynamic properties of the model

Figure 14.1 provides plots of the persistence profiles associated with the system of equations discussed above, looking in turn at convergence to

[5] See Fielding et al. (2012) for the details of the resulting regressions as well as the regressions explaining the dynamics of the 'long-run forcing', exogenous variables (namely, R_t, y_t^g, p_t^{x*} and p_{it}^z, $i = 1, \ldots, 5$) since both sets of regressions are required for the purpose of investigating the system dynamics.

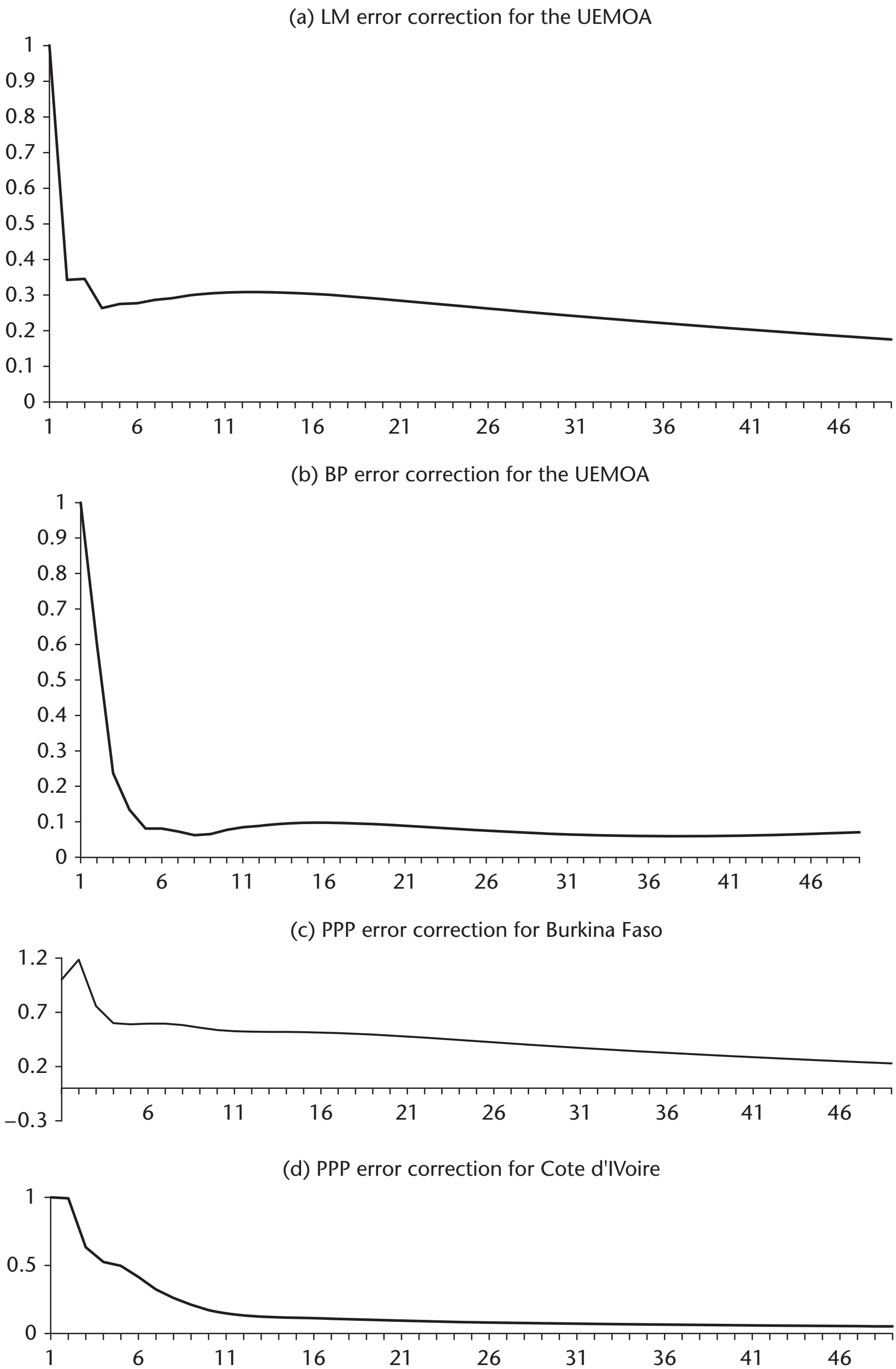

Figure 14.1. Persistence profiles of the long-run relations to the respective unit shocks.

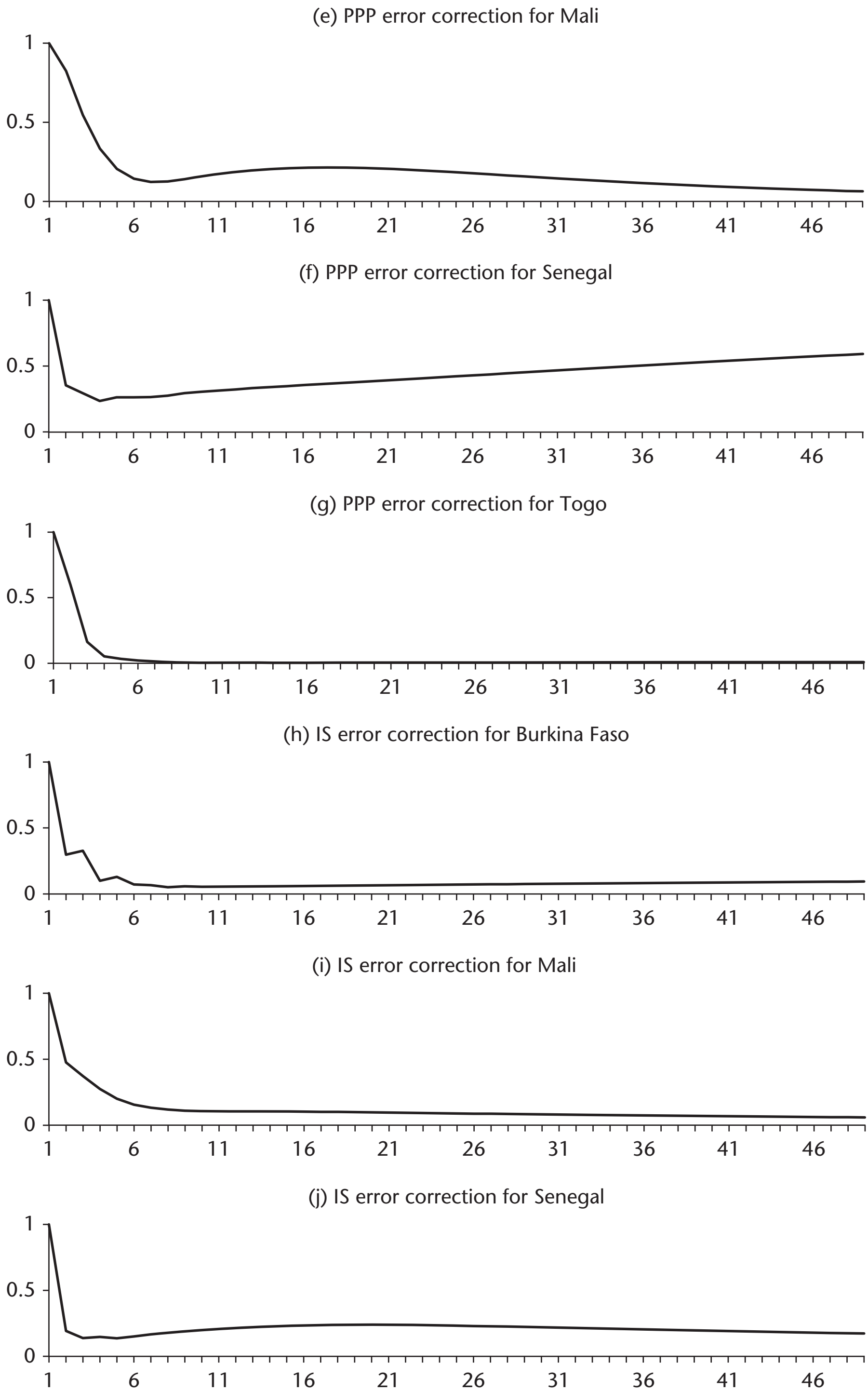

Figure 14.1. Continued

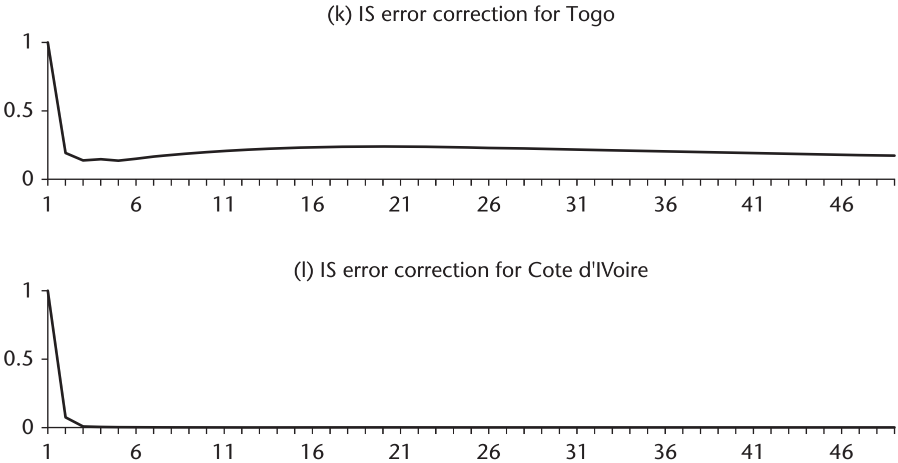

Figure 14.1. Continued

equilibrium of the money market (LM) relationship, of the BP relationship, and of the PPP and IS relationships for the five individual countries. The profiles trace out the effect of a 'typical' shock to the system of equations on the 11 disequilibrium terms. The shock is 'typical' in the sense that it reflects the covariances in the data that are observed across shocks to the different equations in the system in the data. The profiles indicate the speed of convergence to the long-run equilibrium following such a shock, with the profiles scaled to take the unit value on impact and falling to zero in the long-run.[6] The profiles provide a clear indication of the inertias and rigidities that exist in the various markets in the different countries as reflected in the estimated error correction regressions.

Figures 14.1(c)–(g) plots the PPP profiles. Despite the existence of the PPP condition, so that each profile returns to zero eventually, each of the plots exhibits a different speed of adjustment to equilibrium. Differences in the profiles are quantified in 'misalignment' statistics reflecting the size and duration of the disequilibrium trajectory, calculated as the sum of the persistence measures at each time horizon n multiplied by n. This statistic takes values of 452.14, 107.22, 165.85, 617.76, and 12.47 for the PPP relationships for Burkina Faso, Cote d'Ivoire, Mali, Senegal, and Togo, respectively. While there is long-run price neutrality, these differential speeds of nominal adjustments across the countries can have substantial real effects over a short run; so, if there is a shock that causes a substantial initial deviation from PPP, the effects of this are likely to remain for a long time. However, we have

[6] See Lee and Pesaran (1993) for further discussion of persistence profiles.

yet to see whether such shocks are likely to be caused by a typical monetary innovation.

Looking at convergence to equilibrium in the goods markets (captured by Figures 14.1h–l), we again observe different patterns of behaviour in different countries. If we construct summary misalignment statistics for output adjustment in the same form as those for prices adjustment discussed above, we arrive at the values of 104.42 for Burkina Faso, 104.28 for Mali, 259.71 for Senegal, 374.89 for Togo, and 3.50 for Cote d'Ivoire. The statistics reflect extremely rapid convergence in the case of Cote d'Ivoire (within two to three quarters) but much slower convergence in Senegal and Togo.

Figure 14.2 presents the dynamic properties of the system in a slightly different way by focusing on the impact of a specific shock. The figure

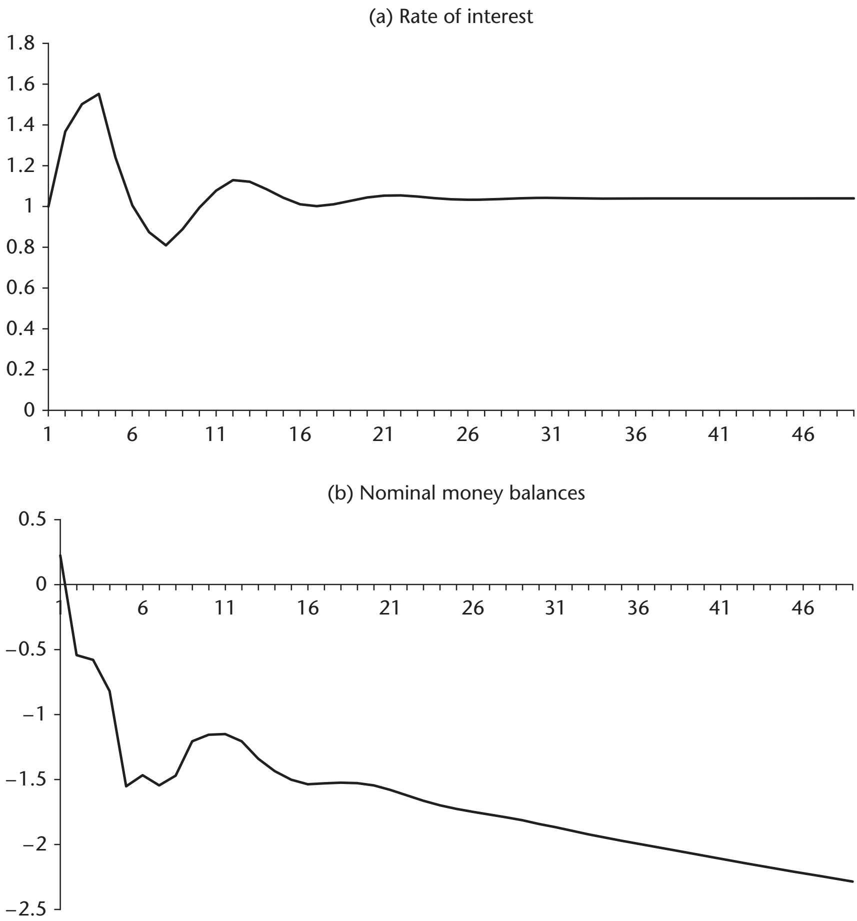

Figure 14.2. Impulse responses to a unit monetary shock.

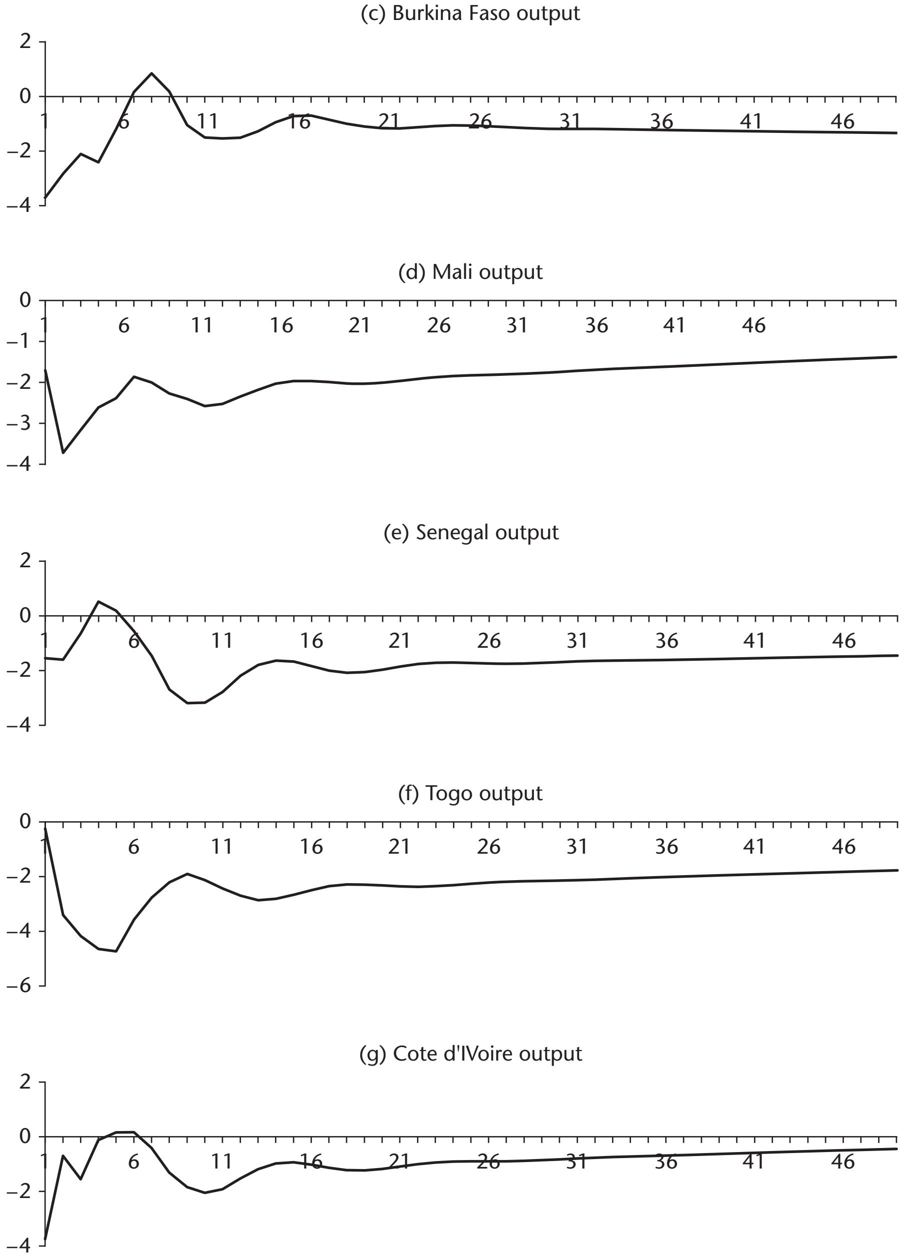

Figure 14.2. Continued

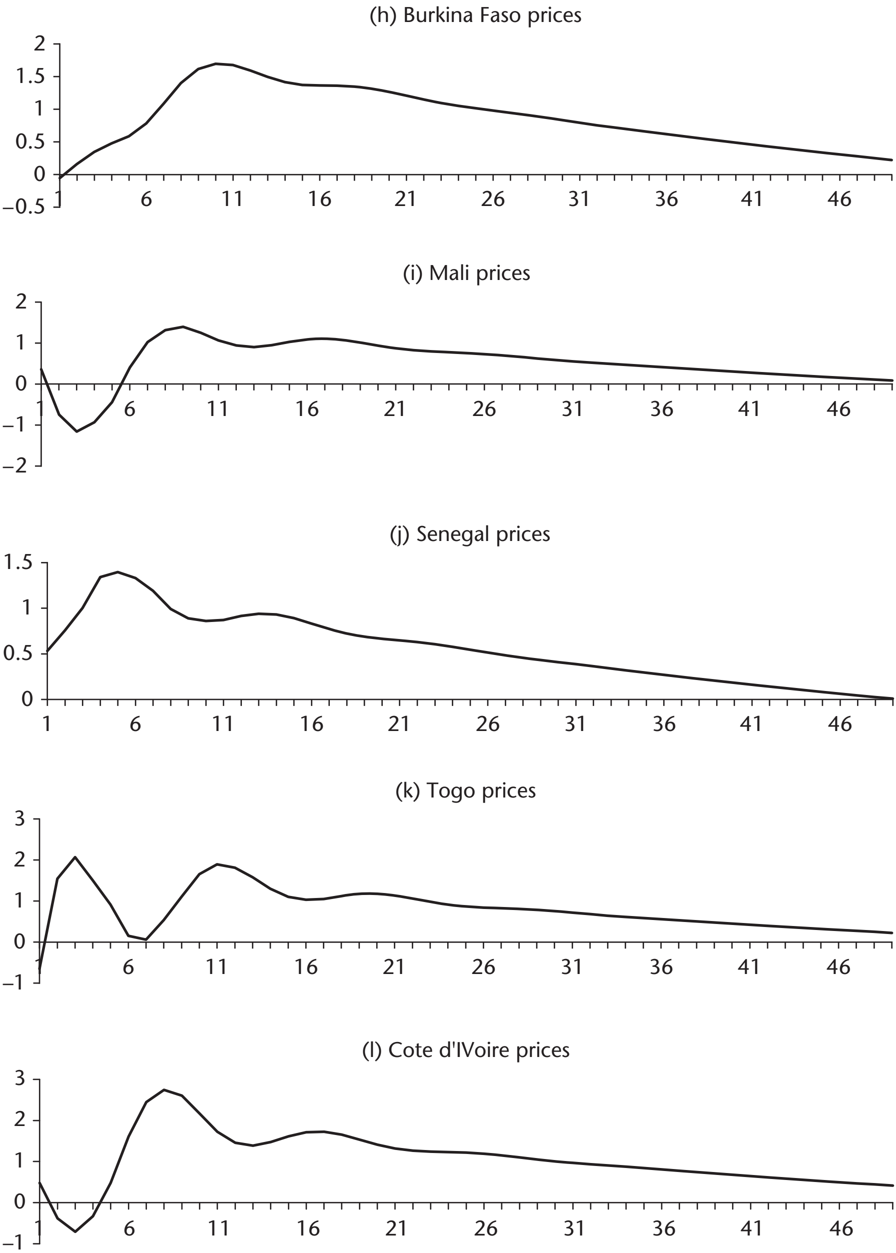

Figure 14.2. Continued

shows the generalized impulse response (GIR) analyses of the 11 endogenous variables to a shock to the interest rate equation. A GIR analysis shows the effect of a shock to a particular equation, taking into account the shocks to other equations in the system that are 'typically' observed in the data. Further, in this case, the interest rate is exogenously determined, so the shock to the interest rate equation is independent of the other shocks to the system, and can be interpreted straightforwardly as a monetary policy shock.

In interpreting these GIRs, it is worth noting that the transmission mechanism for an interest rate shock in our model is rather different from that in the typical OECD country. In our system, the interest rate is strictly exogenous, and the nominal exchange rate is fixed. A rise in the interest rate entails a fall in aggregate demand throughout the monetary union, as indicated by the IS curves. This creates a balance of payments surplus, which necessitates a real exchange rate appreciation. This appreciation can be achieved only through domestic inflation, so a higher interest rate is associated with higher prices, and the price impulse response profiles generally lie above the zero line. In fact, in the event, the dynamics of the model mean that a positive interest rate shock leads to fractionally lower prices in the short run in two out of the five countries (Burkina Faso and Togo), and the impulse response profiles for prices do exhibit some heterogeneity for the first 20 quarters after the shock (Figures 14.2h–l). This is in part a reflection of the heterogeneity of the PPP profiles in Figure 14.1. However, Figure 14.2 also indicates that the long-run price responses are relatively small, with a 1-percentage-point interest rate shock leading to a positive price deviations of just lower than half a percent. Changes in the interest rate do not have a quantitatively significant impact on prices. This result is consistent with the observation in previous work that typical deviations from PPP in most UEMOA countries are not that large. The dynamics of the macroeconomic model that represents the UEMOA contain the potential for substantial persistence in deviations from PPP, but it shows also that monetary shocks causing a large initial deviation are unlikely to be common in practice.

Output falls in all of the countries following the interest rate shock, and by a quantitatively significant amount. Interestingly, since this is not a feature imposed by the structure of the model, output levels recover to the levels close to those that would have been achieved in the absence of the shock after 2–3 years in these countries, indicating that monetary policy has an impact in the short run but there is long-run neutrality. Nevertheless, there is short-run heterogeneity across countries in the response profiles, so a typical monetary policy shock is likely to cause divergent output responses in the short run. The greater divergence in output responses than in price responses across the union's member states is a feature common to previous papers, based on annual data and less detailed macroeconomic models.

14.6 Concluding remarks

The organizing framework of the GVAR allows us to produce a structural model of the countries of the UEMOA with which to investigate some of the costs of monetary union. An important determinant of the net benefit of membership of a monetary union is the extent to which the countries' responses to shocks are similar. The impulse response analysis indicates that there are considerable differences in the dynamic responses of the countries to shocks (in terms of the speed with which each country returns to its equilibrium position). In Senegal and to a lesser extent Burkina, shocks causing deviations from PPP are likely to last for a very long time; in the other countries convergence on PPP is somewhat faster. The persistence of PPP deviations implies substantial *potential* costs from adherence to a single currency, which is at odds with previous studies that have found little relative price variation in countries within the union. The resolution of this puzzle lies in the observation that the potential costs have not been actualized to a very large extent because the external environment seldom throws up shocks generating large deviations from PPP. An example of this is the response of prices to interest rate shocks. The response profiles of the various member countries look very different, but none is large in absolute size because interest rate changes do not have much impact on prices. The absence of large internal price asymmetries in the past is no cause for complacency: if there were ever a shock causing a large deviation from PPP, it would persist for a long time and take a great deal of effort to neutralize. It is still vital that the monetary authorities keep track of price movements in individual countries. Quantifying the degree of asymmetry of past macroeconomic shocks is only part of the story, and no substitute for a fully structural macroeconomic model.

The structural model also identifies a large degree of persistence of shocks causing deviations from internal goods market equilibrium; again the persistence is most marked in Senegal. In this case, the high persistence constitutes an immediate problem for the monetary union because the shocks that cause the deviations from the long-run IS curve are both substantial and frequent. A shock to the interest rate, for example, will lead to large and heterogeneous movements in output in the different UEMOA countries. Effective monetary policy in the future will require acknowledgement of this potential cost of monetary union membership and corresponding policies that can alleviate idiosyncratic recessions in individual UEMOA countries.

The analysis presented provides an interesting case study in the construction of a structural macroeconometric model for developing economies, imposing a relatively sophisticated economic structure on the long-run relations that exist between a group of countries while taking account of a number of data limitations. It also demonstrates the flexibility of the GVAR modelling framework, able to capture the complexities of the interactions between neighbouring nations operating both as autonomous trading partners and within an overarching monetary union.

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15

Competitiveness, external imbalances, and economic linkages in the euro area

*Stéphane Dées**

Euro-area countries have witnessed significant differences in developments in international price–cost competitiveness since the launch of the euro. Also as a result of it, external accounts have differed to a large extent, creating country heterogeneities in the run-up to the 2008 financial crisis. This chapter investigates the sources of external imbalances in the euro-area countries and studies, with the help of a GVAR model, the implications of competitiveness adjustment. The degree of improvement in price–cost competitiveness is assessed under three different types of shocks: a decrease in nominal wages, a negative shock to prices, and an increase in labour productivity. Overall, the results show that a decrease in wages leads to some short-term improvement in the external accounts. The positive supply shock decreasing price levels also leads to some medium-term improvement in the trade balance. Finally, the productivity shock is less powerful on net exports, as the resulting improvement in GDP creates income effects that imply higher imports. Although the impact of these shocks tends to have the expected sign on external balances, their size is small, implying that to get large, significant effects, these shocks would have to be relatively large.

15.1 Introduction

Euro–area countries have witnessed significant differences in developments in international price–cost competitiveness since the launch of the euro.

* Any views expressed represent those of the author and not necessarily those of the European Central Bank or the Eurosystem.

While some countries have continuously gained, other have regularly lost price–cost advantages, reducing their ability to compete on foreign markets. Also as a result of this divergence, external accounts have differed to a large extent in the run-up to the 2008 financial crisis. While differences in current accounts within a monetary union do not necessarily threaten its functioning, since they possibly reflect differences in development levels across member states, the growing and persistent gap in current accounts may signal more fundamental imbalances that necessitate adjustments. Growing intra-euro-area imbalances make first all individual member states more vulnerable to shocks, owing to the strong real and financial linkages between them. Moreover, imbalances threaten the euro area as a whole as countries deviate from the path of sustainable and balanced growth, which is necessary for a smooth functioning of the EMU.

This chapter investigates the sources of external imbalances of euro-area countries and studies, with the help of a GVAR model, the implications of price–cost competitiveness adjustment. The GVAR modelling framework provides an appropriate quantitative tool, as it accounts for the interlinkages within the euro-area countries while considering the euro area within a global system. In comparison with the GVAR model presented in Chapter 2, the exercise is based on a framework where euro-area countries are modelled separately. The GVAR model we use also includes wages, labour productivity, and trade balance, in addition to the usual macroeconomic and financial variables included in the original model. Using this new model, the chapter discusses the response of external imbalances to a set of shocks that tend to improve price–cost competitiveness. The degree of improvement in price–cost competitiveness is assessed under three different types of shocks: a decrease in nominal wages, a negative shock to prices, both being interpreted as positive supply shocks (reducing prices while increasing output at the same time), as well as an increase in labour productivity, creating a more favourable economic environment for firms to compete on external markets.

The chapter is organized as follows. Section 15.2 provides a brief discussion of price–cost competitiveness issues within a monetary union in general and the euro area in particular. It will review ways to restore external imbalances, while considering spillover effects across the various member states. Section 15.3 describes the GVAR model designed for this application, section 15.4 presents the empirical results, and section 15.5 concludes.

15.2 Competitiveness issues and spillover effects in the EMU

The euro area has actively contributed to globalization as its trade openness has increased markedly in the past decades. In the mid-1990s, exports of

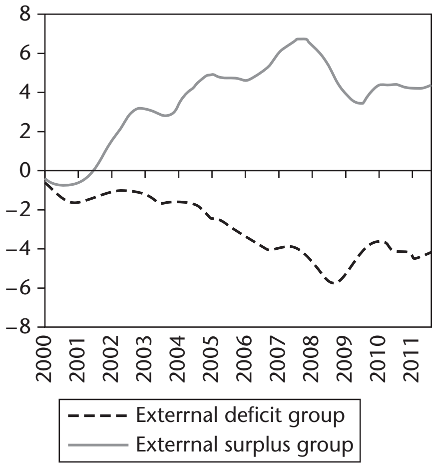

Figure 15.1. Net external accounts by country grouping (4-quarter sums, % of GDP). ECB and Eurostat.

goods and services from the euro area as a whole to the rest of the world were equivalent to around 15% of GDP; in 2010 they amounted to around 23% of GDP.

While the general picture for external price–cost competitiveness of the euro area as a whole was positive, there have been substantial differences across individual countries. Indeed, the recent turbulence in sovereign debt markets can be interpreted as a manifestation of the effects of the severe competitiveness differentials that have emerged over time between countries within the euro area.[1]

An analysis at the euro-area country level shows that while the aggregate euro-area external position has remained close to balance, there has been an increasing divergence between two groups of countries: the 'external surplus group', which takes together countries that had run external current account surpluses over a period of five years ending at the onset of the financial crisis in 2007, and the 'external deficit group', which takes together countries that ran over the same period current account deficits[2] (see Figure 15.1).

[1] In what follows we adopt a relatively narrow definition of competitiveness, i.e. related to relative unit labour costs (for a broader treatment of the issue see, for instance, di Mauro et al., 2010).

[2] The 'external surplus group' includes Belgium, Germany, Luxembourg, the Netherlands, Austria, and Finland. The 'external deficit group' includes Ireland, Estonia, Greece, Spain, France, Italy, Cyprus, Malta, Portugal, Slovakia, and Slovenia. Further details on the analysis of euro-area current accounts during the financial crisis and on the grouping of euro-area countries is available in the box entitled 'A sectoral account perspective of imbalances in the euro area', Monthly Bulletin, ECB, February 2012, pp. 38–43.

Current account deficits could be justified for any country, including those participating in a monetary union, because they do not necessarily imply structural losses in competitiveness. Capital inflows, for example, may be favouring member states with better growth prospects and higher expected returns, related to catching-up processes and successful structural reforms. The simultaneous occurrence of deficits and surpluses in the euro area may therefore be rationalized as the sound circulation of savings within the Monetary Union and the euro has certainly facilitated their financing.

Increasingly, however, larger current account deficits have been associated with significant domestic macroeconomic imbalances and deeper structural problems.

In the euro area, one often-quoted indicator of imbalances across countries is compensation of employees paid by non-financial companies (Figure 15.2). Without implying causality, it is a fact that since the introduction of the euro, there has been a widening of wage trends between countries with an external surplus and countries with an external deficit. This is also confirmed by the cumulated changes in unit labour costs, which jointly reflects developments in productivity and labour costs. Since 2000, unit labour costs have increased by 28% in deficit countries as against 11% in surplus countries. Although part of this differential in unit labour costs growth is justified, as it reflects sustainable increases in income per capita, it might also relate to structural problems and reflect misalignments between developments in nominal variables (wages) and productivity increases. As

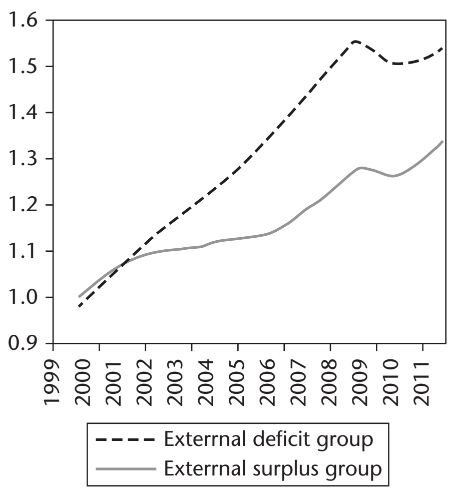

Figure 15.2. Compensation of employees paid by non-financial companies (4-quarter sums, EUR trillions).
ECB and Eurostat.

such, these misalignments may have contributed to the increasing losses of competitiveness in the deficit countries.

In a monetary union such as the euro area, with a single current and a single monetary policy, the main adjustment mechanism—in the absence of a high degree of labour mobility and fiscal transfers across countries—is the competitiveness channel. The competitiveness channel works as follows: following a wage shock or a shock that drives a country's output above its potential, domestic inflationary pressures—on wages and other domestic costs—will give rise to a deterioration in external competitiveness. This will, in turn, gradually reduce foreign demand for the country's exports, such that lower external demand will tend to restore output to its potential level and to dampen previous inflationary pressures. This mechanism remains, however, rather schematic, and available evidence shows that the competitiveness channel appears to require a relatively long period to work through in the euro area. As this may be related to structural rigidities, competitiveness improvement might also require higher productivity growth. Structural reforms are therefore advocated by many institutions to remove rigidities in the labour and product markets (e.g. OECD, 2012, or European Commission, 2012). In particular, policies to ensure flexible wages and prices as well as reforms favourable to productivity growth are regularly promoted as ingredients to the rebalancing (e.g. Trichet, 2008). The debate remains, however, quite open (see di Mauro et al., 2010).

The aim of this chapter is to quantify the impact of lower wages or the effects of reforms that boost output and productivity while restoring external price competitiveness. Before commenting on the results of the model simulations, we will see how the GVAR approach can help model intra-euro area linkages.

15.3 Measuring economic linkages within the euro area with a GVAR model

An analysis of the impacts of adjustments in competitiveness requires a model that accounts for the linkages with the main trade partners and allows for feedback effects between the country adjusting its prices and costs and its competitors. A GVAR model is particularly suitable for this, provided, obviously, that it includes variables that allow the identification of shocks related to competitiveness and external imbalances and the countries that are relevant for the analysis.

Compared to the model analysed in Chapter 2, the GVAR model used in this chapter includes seven variables, four that were included in the original version (real GDP, consumer prices, short-term interest rates, and real exchange rate) and three new variables needed for this particular exercise (wages, labour productivity, and trade balance). Also, instead of treating the euro area as a single economy, this application includes country-specific models for 11 euro-area members states (Germany, France, Italy, Spain, the Netherlands, Belgium, Austria, Finland, Greece, Portugal, and Ireland) together with all the other advanced and emerging economies modelled in the DdPS-GVAR, including the US. The data are of quarterly frequency and cover the period from 1985q1 to 2009q4.

As in Chapter 2, each country *i*'s economy is modelled as a VARX*(p_i, q_i) that includes domestic and foreign variables (x_i and x_i^*), where foreign variables are constructed as a weighted average of variables of the partner countries. The country-specific weights (ω_{ij}) capture the relative importance of each $(N-1)$ foreign economy *j* to the domestic economy *i*. The country-specific VARX* can be written as follows

$$x_{it} = a_{i0} + a_{i1}.t + \sum_{s=1}^{p_i} \Phi_{is} x_{i,t-s} + \sum_{s=0}^{q_i} \Lambda_{is} x^*_{i,t-s} + \sum_{s=0}^{q_i} \Psi_{is} d_{t-s} + u_{it}, \tag{15.1}$$

where $x^*_{it} = \sum_{j=0}^{N} \omega_{ij} x_{jt}$ and d is a vector of observed common factors (e.g. oil prices) and t is a time trend.

In the present application, the vector for domestic variables is given by

$$x_{it} = \left(w_{it}\ y_{it}\ p_{it}\ prod_{it}\ tb_{it}\ rer_{it}\ r_{it}\right), \tag{15.2}$$

where w_{it} denotes compensations of employees, y_{it} is real GDP, p_{it} is consumer prices, $prod_{it}$ is labour productivity, tb_{it} is the trade balance as a percent of GDP, rer_{it} is the real effective exchange rate, and r_{it} is the short-term interest rates. All variables are in logarithms except tb_{it}.

The vector of foreign variables for each economy except the US is given by

$$x_{it} = \left(y^*_{it}\ p^*_{it}\ r^*_{it}\right). \tag{15.3}$$

The vector of foreign variables for the United States is given by:

$$x_{it} = \left(y^*_{it}\ p^*_{it}\ rer^*_{it}\right). \tag{15.4}$$

The real price of oil is also included as the observed common factor, d_t.

15.4 Empirical results

Using the GVAR model detailed above, we consider three main scenarios:

- Scenario 1: gain in cost competitiveness: a 1% shock to nominal wages that lowers unit labour costs;
- Scenario 2: gain in price competitiveness: a 1% shock to domestic prices that lowers relative prices;
- Scenario 3: productivity gains: a 1% increase in domestic productivity that boosts output while lowering prices (i.e. a supply shock).

The shocks have been identified through a Cholesky decomposition following Dées et al. (2007). They have been simulated as one-standard-deviation shocks and the results have been adjusted *ex post* (based on the log-linearity of the model) to reflect 1% shocks for the sake of simplicity and comparison.

All these shocks lead to a gain in external price–cost competitiveness. Theoretically, we expect two main forces at play. First, the competitiveness channel should lead lower domestic prices (either resulting from lower wages or from another type of supply shock) to improve the external competitiveness of the domestically produced goods and lead to higher net exports. These volume effects are, however, limited by price effects, as lower export prices tend to worsen the nominal trade balance, at least in the short term. The second main channel relates to the positive effects these supply shocks have on output. Higher output leads to higher income, which in turn tends to lower net exports, via higher imports. The competitiveness and the income channels go therefore in opposite directions, so that the overall impact on trade balance is a priori uncertain. If the competitiveness channel dominates, lower costs and prices should improve the trade balance. If the income channel dominates, the trade balance should deteriorate. Moreover, the monetary authority, in response to lower inflation, is expected to cut nominal interest rates, which will put appreciation pressures on the exchange rate owing to interest rate differentials. This exchange rate appreciation will limit the gain in price competitiveness, at least in the dynamic adjustment toward the long-term response.

All the shocks simulated in this exercise are implemented in a large euro-area country belonging to the external deficit group. To remain general, the simulations have been implemented independently for Spain, France, and Italy. The results reported here are averages of these individual simulations. Each country response does not differ in sign and significantly in size, so that the results reported remain valid whatever country is considered.

A fourth simulation (Scenario 4) has also been performed in order to assess the impacts of simultaneous shocks in the external deficit group as a whole. This allows us to also consider the consequence of the coordination of reforms. Only the results relative to the simultaneous shock to wages in the external deficit countries are reported here.

15.4.1 *Scenario 1: gain in cost competitiveness*

The cost-competitiveness scenario is simulated via a negative shock to wages. This shock can be interpreted as a positive supply-side shock that leads to higher competition in the labour market, thereby lowering the cost of production for firms. As expected, the decline in nominal wages has downward impacts on unit labour costs that are lower by more than 2% after 10 years (Table 15.1). Relative prices are also lower by around 1% as a result of lower domestic prices. This supply shock has positive impacts on real GDP, which is higher by more than 1.5 p.p. after 10 years. In the short term, however, lower wages have negative impact on income, leading to some slight decline in real GDP after one year.[3] The shock has some positive impacts on the trade balance, which is higher by 0.3 p.p. of GDP after 1 year and 0.2 p.p. after 5 years. In the long term, however, the trade balance is close to baseline.

The euro area as a whole benefits from this shock in terms of output, as the rest of the euro area's real GDP is higher by 1.1% after 10 years. At the same time, the gain in competitiveness in this large external deficit country has limited effects on the trade balance of the rest of the euro area, as trade balance is lower by 0.1 p.p. of GDP after 1 and 5 years, but remains close to balance after 10 years.

Table 15.1. Scenario 1: impacts of a 1% negative shock on wages in one large euro area external deficit country.

	After 1 year	After 5 years	After 10 years
Large external deficit country			
Real GDP	−0.1	1.0	1.7
Unit labour costs	−1.5	−1.7	−2.1
Relative prices	−0.4	−0.5	−0.9
Trade balance	0.3	0.2	0.0
Rest of the euro area			
Real GDP	−0.1	0.2	1.1
Trade balance	−0.1	−0.1	0.0

[3] The shocks in the GVAR have been identified through a Cholesky decomposition. However, given the relatively small size of the VAR, the shock to wages could also possibly reflect a labour-demand shock.

15.4.2 *Scenario 2: gain in price competitiveness*

The second scenario envisages a shock to prices directly. This shock can also be interpreted as a positive supply-side shock, that could result, for instance, from higher competition on the product markets. Higher price competitiveness, which traditionally is one of the main determinants of export performance, contributes to higher exports.

Table 15.2 shows the impact of the decline in prices on the external deficit country. Lower prices have a direct impact on relative prices, which are lower by 0.7% after one year. As a positive supply-side shock, real GDP is also higher permanently. The increase in activity tends to limit the rebalancing of the external accounts through the income effects in the short-term. However, in the medium- to the long-term, the large relative price effect (−1.4% after 10 years) leads to a permanent increase in the trade balance (+0.4 p.p. of GDP after 10 years).

The impact on the rest of the euro area remains overall limited, both for output and for the trade balance. However, owing to the permanent impact on the trade balance in the external deficit country, trade balance is negatively affected in the rest of the euro area (−0.2 p.p. of GDP after 10 years), participating in the overall rebalancing within the euro area.

15.4.3 *Scenario 3: productivity gains*

A labour productivity shock increases the effectiveness of workers, allowing the firms to produce more output with a given level of employment. As a result, monopolistically competitive firms can reduce their prices without changing their price mark-up. Theoretically, the impact of productivity shocks on the trade balance is unclear, as higher price competitiveness that boosts exports is partly counterbalanced by income gains, leading to higher imports. The overall impact also depends on whether the productivity

Table 15.2. Scenario 2: impacts of a 1% negative shock on prices in one large euro area external deficit country.

	After 1 year	After 5 years	After 10 years
Large external deficit country			
Real GDP	0.1	0.3	0.5
Unit labour costs	−0.8	−0.8	−0.9
Relative prices	−0.7	−1.1	−1.4
Trade balance	0.0	0.2	0.4
Rest of the euro area			
Real GDP	0.0	0.0	0.1
Trade balance	−0.1	−0.1	−0.2

Table 15.3. Scenario 3: impacts of a 1% positive shock on productivity in one large euro area external deficit country.

	After 1 year	After 5 years	After 10 years
Large external deficit country			
Real GDP	0.4	1.0	0.6
Unit labour costs	−1.0	−0.7	−0.5
Relative prices	−0.5	−0.5	−1.0
Trade balance	−0.1	−0.2	0.1
Rest of the euro area			
Real GDP	0.1	0.5	0.1
Trade balance	−0.0	−0.1	0.0

shocks originate from the tradable or non-tradable sector. We cannot investigate these different aspects with the GVAR, but the shock to productivity performed here gives the average impact we could expect based on historical evidence.

The impact of a 1% increase in labour productivity on prices (Table 15.3), and therefore on relative prices, is very similar to those of Scenario 1 (Table 15.1). Unit labour costs fall to a lesser extent. The impact on GDP is positive immediately, although the long-run impact is somewhat more limited compared with the wage shock. As a result of a more favourable income effect, the effect on trade balance is negative after 1 and 5 years, but becomes slightly positive after 10 years.

The impact on the rest of the euro area is also positive as far as real GDP is concerned. This shows positive spillover effects from the large external deficit countries to the rest of the area. However, the trade balance is also negative in the short and medium term (i.e. after 1 and 5 years), showing the large impact of income effects. Overall, the GVAR simulations, as they account endogenously for the rest of the world, show that the productivity shock tends to lead to a slight deterioration of the trade balance of the euro area as a whole, benefitting the rest of the world. This effect is nevertheless temporary, as in the long term (after 10 years) only the country where the productivity shock originates is the beneficiary of the productivity gains (in terms of external balances and output).

15.4.4 *Scenario 4: coordinated reforms increasing cost competitiveness*

While non-negligible, the spillover effects to other countries remain relatively limited when we consider the consequences of the competitiveness adjustment in a single country. Scenario 4 investigates what would happen when several countries adjust simultaneously. This scenario reflects the

Table 15.4. Scenario 4: impacts of a 1% negative shock on wages in a all euro area external deficit countries.

	After 1 year	After 5 years	After 10 years
Euro area external deficit countries			
Real GDP	0.1	0.5	0.1
Unit labour costs	−1.2	−1.5	−1.7
Relative prices	−0.2	−0.3	−0.5
Trade balance	0.1	0.1	0.0
Euro area external surplus countries			
Real GDP	0.1	0.3	0.0
Trade balance	0.0	−0.0	−0.1

possibility of some synchronization of reforms among a number of euro-area countries.

This scenario is conducted via a reduction in the wages in all euro-area countries that belong to the external deficit group; namely Greece, Ireland Italy, Spain, Portugal, and France. This group constitutes roughly half of the euro area. The shock simulated is implemented as Scenario 1 but now applies to all the above countries at the same time.

The impact on unit labour costs is rather similar when applying the shock to all deficit countries or to only one large country of the group (Table 15.4). The impact on price competitiveness is also positive, as relative prices are lower. The impact is, however, more limited in the coordinated case as the shock applies to countries that are also competitors. Higher price competitiveness has a positive impact on adjusting countries' trade balance and slightly negative in the rest of the euro-area countries. The improvement in price competitiveness has a positive impact on real GDP in the adjustment countries of around 0.5% after 5 years. The impact on the rest of the euro area is also positive, showing positive spillovers, although the increase in GDP in the rest of the euro-area countries is much lower than that registered in the adjustment countries.

15.5 Conclusions

The financial crisis has emphasized the need to correct excessive external imbalances for several euro-area countries, which lost price–cost competitiveness during the first decade of monetary union. In particular, unit labour costs have grown at a relatively high pace in countries that have been under stress. While for the euro area as a whole, unit labour costs grew by 1.5% on average between 1999 and 2007, in countries such as Greece, Portugal, Spain, and Ireland the increases were close to double that rate. This increase in unit labour costs reflected high nominal wage growth and in some countries poor productivity performance.

In a monetary union, with a single currency and a single monetary policy, the main adjustment mechanism—in the absence of a high degree of labour mobility or cross-country fiscal transfers—is the competitiveness channel. Positive supply-side policies are therefore expected to improve competitiveness, by lowering unit labour costs and decreasing relative export prices.

Using a GVAR model, this chapter has shown that supply shocks (lower costs/prices or higher labour productivity) have positive impact on activity and tend to improve external accounts of individual member countries. However, the associated positive income effects tend to absorb part of the increase in net exports through higher import demand. As a result, large shocks would be necessary to get large corrections in external imbalances. The limit of this modelling exercise relates to the fact that the GVAR simulations remain valid for shocks that are in line with past developments. Larger adjustments than those observed in the past might imply nonlinear effects that the GVAR cannot capture.

Finally, worsening price–cost competitiveness is not the only source of imbalances in the euro-area countries. Other factors—not related to prices or costs—have played a role in the emergence of external imbalances in some euro-area countries. For instance, non-price competitiveness seems to have played a role, in France (see Fontagné and Gaulier, 2008 or di Mauro et al., 2010). Large current account imbalances have also reflected demand booms fuelled by credit expansion and house price bubbles, as in Spain. However, these factors remain beyond the scope of the present chapter and are left for future research.

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16

Forecasting the Swiss economy with a small GVAR model

*Katrin Assenmacher**

16.1 Introduction

The recent development of global vector autoregressive (GVAR) modelling provides a compact strategy to model foreign countries alongside the domestic economy. Co-integrating VAR (CVAR) models have been widely used for forecasting and policy analysis. The GVAR methodology allows CVAR models for different countries to be linked with each other to study international interactions.[1]

One advantage of VAR-type models is that they treat all variables as endogenous without imposing detailed economic relations on the dynamics. This lack of restrictions, however, results in a large number of parameters that have to be estimated. In practice, therefore, only models with a limited number of variables are feasible. For small, open economies, however, not only domestic variables have to be taken into account, but also foreign developments are important, which increases the number of variables that need to be modelled. To keep the size of the model manageable, foreign variables are usually treated as weakly exogenous. If the model is to be used for forecasting, a scenario for the evolution of the world economy over the forecast period has to be designed, on which the forecasts then are conditioned.

From a theoretical perspective, however, this approach is not fully satisfactory. First, the predictions for the exogenous variables may not be consistent with the model for the domestic economy, as they may come from

* This chapter is based on joint work with Daniel Geissmann. The views expressed in this chapter are those of the author and do not necessarily represent those of the Swiss National Bank.

[1] A detailed exposition can be found in Pesaran et al. (2004) and Dées et al. (2007).

a completely different modelling approach than that used for the endogenous variables. Second, possible feedback from the endogenous variables to the exogenous variables is not taken into account. Moreover, interactions between the domestic and the foreign variables cannot be investigated as they are excluded by assumption. Thus, a coherent modelling approach, taking into account the relations between the domestic and the foreign economies, would be preferable.

This chapter embeds a co-integrating VAR model for Switzerland into a GVAR model consisting of Switzerland's three largest trading partners; namely the euro area, the US, and Japan. It assesses the forecasting performance of this GVAR model for Swiss inflation and output growth. Though the GVAR approach is theoretically attractive and consistent, it is uncertain whether for Swiss variables it improves forecast precision compared to other modelling approaches for two reasons. First, treating all variables as endogenous increases the number of free parameters, which tends to deteriorate forecast performance. Second, Switzerland is a small, open economy, which limits the gains from modelling the feedback from Swiss variables to the foreign economies. Nevertheless, we find that the forecasting performance of this small GVAR model is—contrary to claims that have been made, for example, by Dennis and Lopez (2004a, b)—commensurate to that of other widely used forecasting approaches, confirming that the GVAR methodology is useful for forecasting and policy analysis.

16.2 The Swiss GVAR model

We start from a CVAR model for the Swiss economy that includes six endogenous and five exogenous variables. A similar model is used by the Swiss National Bank (SNB) as one of the models contributing to its published conditional inflation forecasts.[2] The choice of the variables in the model is motivated by the objective to forecast Swiss inflation and real GDP growth for monetary policy purposes. We therefore include, in addition to real GDP and the change in the consumer price index (CPI), the three-month Libor as the monetary policy interest rate and the 10-year government bond yield in the Swiss model. To reflect export demand, we consider the exchange rate of the Swiss franc to the euro, deflated by the Swiss CPI, as another endogenous variable. As Switzerland followed a monetary target from 1976 to 1999 and monetary aggregates still play an important role in the new

[2] For a detailed description of a Swiss CVAR model see Assenmacher-Wesche (2008) and Assenmacher-Wesche and Pesaran (2009). The specification of the model in this chapter differs slightly from the model described in these two papers to facilitate the link to the CVAR models for the foreign countries.

monetary policy framework (see Jordan et al., 2001), we also add real M3 as an endogenous variable.[3] The exogenous variables in the Swiss model are foreign real GDP, the change in the foreign price level, the foreign three-month and ten-year interest rate, and the oil price. The precise definition of the exogenous variables will be discussed later in more detail, when the CVAR models for the foreign economies have been introduced.

To model Switzerland's relations to the rest of the world, the Swiss CVAR model is linked to similar models for the euro area, the US, and Japan. For two reasons we consider a much smaller set of countries than the original GVAR model, proposed by Pesaran et al. (2004), which includes 26 countries. First, we want to focus on the gain in forecasting precision for the domestic variables that is obtained by explicitly modelling the exogenous variables and their linkages with the domestic economy. It thus seems reasonable to restrict the GVAR to the most important trading partners of Switzerland.[4] Second, to evaluate out-of-sample forecasts over a reasonably long period, reliable data over a sufficiently long observation period are needed, which are easier to obtain and of better quality for a smaller set of developed countries. Of course, there is a trade-off in the number of countries included. On the one hand, the model is easier to handle if the analysis is limited to only a few countries. Moreover, fewer countries mean a smaller number of free parameters, which generally improves forecast performance. On the other hand, by considering only a limited set of countries, relevant information that might improve forecast performance is disregarded.

The models for the euro area, the US, and Japan are specified in a similar way as the Swiss model but do not include a monetary aggregate. The GVAR approach is sufficiently flexible to allow for different sets of variables in the individual country models. We will discuss later how this can be handled when the country models are linked to each other. Each model for the foreign economies includes real GDP, the quarterly rate of change in the consumer price index, a three-month interest rate, and the ten-year government bond yield. In addition, the models for the US and Japan comprise the bilateral real exchange rate to the euro as another endogenous variable. We do not consider a monetary aggregate in the models for the euro area, the US, and Japan because monetary targeting has not played such a prominent role as in Switzerland over the full sample period in those countries.

[3] Peytrignet and Stahel (1998) find that money demand functions for both M2 and M3 are stable over the period 1977–1997, but M3 has better forecasting properties for inflation. Kirchgässner and Wolters (2010) confirm the stability of M2 and M3 for the period from 1983 to 2008. Nevertheless, in the aftermath of the financial crisis M2 showed unusually high growth rates of up to 40%, whereas M3 was less affected. We therefore use M3 in the Swiss model.

[4] Among the 24 largest trading partners of Switzerland (see Fluri and Müller, 2001), the euro area accounts for about 60% of Swiss foreign trade. The US represents the second largest trading partner with 15%, whereas Japan, with 5%, is included to reflect developments in Asia.

The exogenous variables provide the link between the individual country models. In a GVAR all variables are determined endogenously. Thus any variable that is considered as exogenous to one country will be specified as an endogenous variable in another country's model. The oil price is considered as exogenous for Switzerland, Japan, and the euro area. It is included as an endogenous variable for the US because the US is the largest economy in our model and therefore likely to have the biggest influence on the oil price from the demand side.

Foreign GDP, foreign inflation, and foreign interest rates in the Swiss model are constructed as the trade-weighted averages of the respective variables for the euro area, the US, and Japan. These variables therefore are determined in the corresponding equations of the other countries' models. In the Swiss model, however, these variables do not enter individually, but as trade-weighted averages. The use of trade-weighted averages saves degrees of freedom, which becomes particularly relevant if the model includes a large number of countries. It reflects the assumption that the importance of a certain country for the domestic economy is higher the higher the trade volume with this country is. We use the same weights for the construction of all variables, though it would be possible to use different weights to aggregate, for instance, financial variables. We also refrain from using time-varying weights because with fixed weights we avoid having to predict the change in trade weights during the forecast period.[5] Moreover, for the countries considered in this study, trade weights remained relatively constant over the sample period we investigate here.

Finally, we have to model the exchange rate relations between the countries in the GVAR. We choose the euro as the base currency for the GVAR, implying that the models for Switzerland, the US, and Japan include the bilateral real exchange rate to the euro as an endogenous variable. To close the model, we enter the trade-weighted real exchange rate as an exogenous variable for the euro area. In that way, we ensure that the exchange rate is not overdetermined, as for N countries only $N-1$ bilateral exchange rates exist that can move independently.[6]

Finally, Swiss real M3 is determined solely in the Swiss part of the GVAR model. It does not enter any of the foreign models as an exogenous variable,

[5] When using time-varying weights, a specific year needs to be chosen to solve the GVAR as the weighting affects how the coefficients on the exogenous variables are assigned to the global model.

[6] We cannot enter a bilateral exchange rate as an endogenous variable in the case of the euro area since it is already implicitly determined by the exchange-rate equations for the other countries. See Pesaran et al. (2004) for a discussion of this issue. Alternatively, we could have included the weighted exchange rate in the Swiss model and the bilateral exchange rates to the Swiss franc in the models for the other countries. Since Switzerland is small, however, the Swiss exchange rate is unlikely to have good explanatory power in the foreign models. We therefore did not choose this specification.

meaning that we do not assume any international interactions resulting from money demand. This illustrates that not all variables have to be treated symmetrically when setting up the global model. In particular, the domestic model can be specified in more detail and be linked to foreign models that capture only the most relevant channels of international transmission, i.e. trade and financial flows.

Putting all country models together, the model can thus be written in the form of a global VAR, in which the coefficients of the full global model are estimated under restrictions that are imposed through the use of trade-weighted foreign exogenous variables. Having estimated the country-specific CVAR models, the coefficients in the global model are constructed by taking the estimates from the country models and the same weighting that has been applied to aggregate the exogenous variables. For instance, the coefficient on, say, euro-area GDP in the Swiss equations is constructed by multiplying the coefficient on foreign GDP in this equation with the respective weight for euro-area GDP that has been used in the construction of the variable. As in the GVAR, all variables are endogenous; the model can be used for forecasting and impulse-response analysis like a normal VAR model.

16.3 Data and specification

The data start in the first quarter of 1976 and end in the third quarter of 2011.[7] Except for the interest rates, all variables are in logarithms. Interest rates are expressed as $0.25(1+i/100)$, where i is the annual interest rate in per cent, and are thus in the same unit as the quarterly inflation rate. We use country-specific average trade weights for the years 1997–1999. The trade weights are calculated as the average share of one country in the trade with one of the other countries.

Unit root tests show that in general the variables can be considered as non-stationary. The main exception is the inflation rate, which seems to be stationary for Switzerland but integrated of order one, $I(1)$, for the other countries. To maintain the symmetry of the model, we decided to consider inflation for all countries as $I(1)$.

As we will compute recursive out-of-sample forecasts, we have to make sure that when calculating the forecasts we do not use information that was available only later. In the following, we determine the specification for

[7] Data for Switzerland are from the Swiss National Bank. The data for the euro area and the US are from the OECD's Main Economic Indicators. For Japan, the CPI and real GDP are taken from the IMF's International Financial Statistics. Interest rates and exchange rates are from the BIS database. The oil price is the average of daily data obtained from the SNB's data base. Trade volume is computed as the average of the exports and the imports between two countries and is from the Direction of Trade Statistics of the IMF.

the GVAR model using data spanning 1976q1 to 2002q2. We chose 2002q3 as the starting date for our forecasting exercise because from that date on we have exogenous scenarios for the world economy from the SNB that we will use when comparing the forecasts from the GVAR to alternative modelling approaches. The observations from 2002q3 to 2011q3 are reserved to evaluate the model's forecast performance. In that way, we ensure that we do not use information in the specification of the model that would not have been available at the time the forecasts were made.

We include a trend that is restricted to the co-integration space. As suggested by the Schwartz criterion, the models are estimated with a single lag for the endogenous and the exogenous variables for all countries. F-tests confirm that the hypothesis of no residual autocorrelation cannot be rejected when using this lag length. The maximum eigenvalue test recommends three co-integrating relations for Japan and two co-integration relations for the other countries at the 5% significance level. Nevertheless, with a total of nine co-integrating relations the persistence profiles (see Lee and Pesaran, 1993) show high persistence. These equilibrium relations are therefore unlikely to improve forecast performance, as the equilibrium correction mechanisms work too slowly. We therefore reduce the number of co-integrating relations and impose only two exactly identified co-integrating relations for Switzerland and one for the euro area, the US, and Japan.

As mentioned in Chapter 2, one potential problem when setting up a small GVAR model is weak exogeneity. With the single exception of foreign GDP in the Swiss model, we find that weak exogeneity of the foreign variables cannot be rejected for any country in our group, not even for the US or the euro area, which are large economies.[8] We therefore conclude that the assumptions under which the GVAR is estimated are not violated.

16.4 Forecasting with the Swiss GVAR

In the forecasting exercise, we focus on the Swiss CPI and Swiss real GDP. We evaluate forecast performance according to the root mean squared forecast error (RMSFE). We consider cumulative changes, i.e. we assess how well the model has predicted the price level and the level of output up to 12 quarters into the future. Though the GVAR also delivers forecasts of real GDP and inflation for the other countries, we do not evaluate them, as our interest lies in the domestic economy.[9]

[8] By contrast, Giese and Tuxen (2009) find more rejections of weak exogeneity in a GVAR model for the UK, the US, the euro area and Japan.

[9] See Granger and Jeon (2007) for a discussion of the different dimensions according to which a global model can be evaluated.

In line with SNB practice, we consider a forecast horizon of 12 quarters. One has to bear in mind, however, that forecast precision deteriorates with increasing horizon and model-based forecasts tend to contain little information beyond the one-year horizon. To generate the forecasts, we proceed as follows: starting with data until 2002q2, the GVAR model is re-estimated recursively by adding one quarter of data and at each iteration used to generate one- to twelve-step-ahead forecasts. As a result, we have 37 forecasts that can be evaluated at the one-quarter horizon and 26 for the 12-quarter horizon. When interpreting the RMSFEs, one has to be aware that the forecast evaluation period contains several challenges for a forecasting model.[10] As long as the development of inflation and GDP growth differs from the patterns that are reflected in past data, any model-based forecasts will have difficulties to predict them.

We compare the forecast performance of the GVAR with two alternative model versions. Because of its relatively large size, a GVAR is not optimized to produce point forecasts. For this reason, Dennis and Lopes (2004a, b) conjecture that forecasts using exogenous variables from other sources instead of modelling them in the context of a GVAR are likely to outperform forecasts from a global model if the objective is predicting the domestic economy. Our forecast exercise is designed to address these concerns.

The first alternative model is the Swiss CVAR, which is supplemented with forecasts for the exogenous variables from a VAR model in these exogenous variables without explicitly modelling the three foreign countries. Second, we compare the forecasts from the GVAR with those from the Swiss CVAR that draw on paths for the exogenous variables as they were specified in the world economy scenarios, which the SNB uses for its quarterly inflation forecasts.[11] These world economy scenarios are partly derived from model simulations, but also include judgement about the future evolution of the world economy. Such judgement may come from any source of information, such as, for instance, central bank statements on the future prospects for monetary policy.

[10] As will be evident later, the impact of the financial crisis on output and inflation is difficult to capture with purely model-based forecasts. While inflation had quickly increased to 3% in 2008q3, it turned negative in 2009. Moreover, in 2009 Switzerland experienced the deepest fall in real GDP since 1975.

[11] See SNB Quarterly Bulletins, various issues. The world economy scenarios specify paths for the oil price as well as output, inflation, and interest rates in major economies. Note that the definition of the variables in the SNB's scenarios does not always exactly match the definition of the variables in the Swiss CVAR model. In particular, the long-term interest rate is the German interest rate and not an average of the US, euro area, and Japanese rate. The short-term interest rates from the SNB scenarios cover only the US and the euro area, but not Japan. Inflation is for the G7 countries and thus relates to a slightly larger number of countries than the GVAR. Nevertheless, these scenarios can be regarded as representative for the development of the economies covered in the GVAR. If anything, the forecast performance should improve when these inconsistencies are not present.

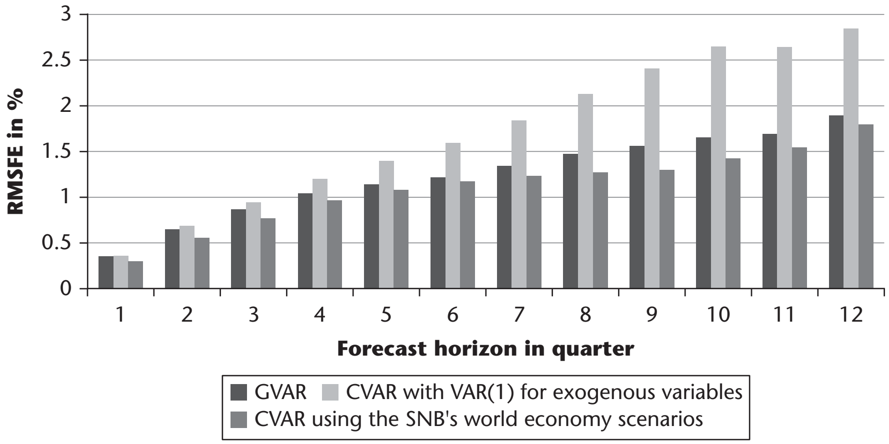

Figure 16.1. RMSFE for the Swiss CPI.

Recursive forecasts from 2002q3 to 2011q3, based on expanding observation windows. Initial sample period: 1976q1 to 2002q2.

Figure 16.1 shows the RMSFEs for the Swiss price level from the GVAR and the two alternative versions of the Swiss CVAR model. With respect to the CPI, the GVAR and the CVAR based on the SNB's world economy scenarios deliver comparable RMSFEs. By contrast, a VAR of order one to predict the exogenous variables leads to RMSFEs that are up to 60% higher. Not surprisingly, the RMSFE increases with the forecast horizon. While for the GVAR the RMSFE is 0.35% at the one-quarter horizon, it is already quite large, with 1% at the four-quarter horizon. This means that when we forecast an inflation rate of 1% one year ahead, the realization will be in the interval from 0% to 2% in 95% of the cases. Nevertheless, all models considered here forecast more precisely than simple models like an autoregressive or a random-walk model, which are often considered as benchmarks in the literature (see Assenmacher-Wesche and Geissmann, 2012).

Figure 16.2 compares the RMSFEs for Swiss real GDP from the GVAR and the two alternative models. For real GDP, all models achieve a broadly similar forecast performance, especially at shorter forecast horizons. Also here the forecasts based on the world economy scenarios generally achieve the lowest RMSFE, with the GVAR giving a slightly higher RMSFE, while the VAR(1) in the exogenous variables leads to a clearly worse performance. Considering the rest of the world as a single block without taking into account international interactions, as the VAR(1) model does, thus seems to introduce an aggregation bias, which deteriorates forecast performance more than the large number of parameters in the GVAR that result from modelling the foreign countries explicitly.

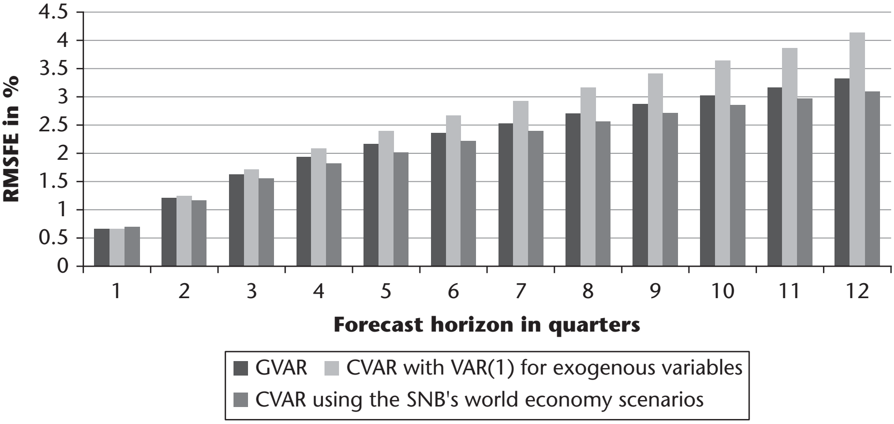

Figure 16.2. RMSFE for real GDP.

Recursive forecasts from 2002q3 to 2011q3, based on expanding observation windows. Initial sample period 1976q1 to 2002q2.

Surprisingly, the forecasts relying on the SNB's scenarios generally attain the lowest RMSFEs, though they are not based on a fully consistent methodology. One reason for this may be that the world economy scenarios contain more information than the past data on which the other two models are based. The scenarios are derived for the SNB's monetary policy assessment of the respective quarter, which takes place in mid-March, mid-June, mid-September, and mid-December. They draw on information that is available up to a few weeks before the monetary policy assessment and thus include information on the foreign economies that has arrived during the first two months of the quarter.

Another possible explanation is that the SNB's world-economy scenarios generally suppose that interest rates and inflation converge to some equilibrium value in the long run and thus exhibit stationary behaviour, whereas the two other models consider inflation and interest rates as non-stationary. This can have a major influence on the forecast properties, especially at long horizons, since the GVAR and the CVAR/VAR(1) model do not impose a reversion to their long-run mean on these variables.

A third explanation for the better forecast performance of the scenario-based forecasts is the forecasting performance during the financial crisis. When only data before the start of the financial crisis in summer 2007 are considered, the GVAR performs slightly better than the scenario-based forecasts up to a horizon of six-to-eight quarters. By contrast, when the full sample is used, the scenario-based forecasts outperform the purely model-based approaches. Though neither model includes variables reflecting the health of the financial sector, the exogenous scenarios offer an opportunity to include such information in the paths for the expected evolution of the world economy that may help to improve forecasts for Switzerland. Nevertheless, it has to be taken into account that events like the financial crisis, where forward-looking information was available that is not adequately captured in past data, are rare.

Summing up, the GVAR model delivers RMSFEs in a comparative magnitude to plausible alternative models, also in a realistic forecast setting. The GVAR approach can therefore be regarded as a valid alternative to simpler models for the domestic economy.

16.5 Conclusions

In this chapter we assessed the forecast performance of a GVAR model and compared it to two alternative models. Using the Swiss country-specific part of the GVAR and supplementing it with a simple VAR(1) model for the exogenous variables produces less precise forecasts than the GVAR. Thus, there is an advantage to modelling the rest of the world, even when the primary interest is in forecasting the domestic economy. This is remarkable because the GVAR approach is a complex modelling framework involving a large number of variables and is estimated under restrictions on the cross-country linkages that cannot be tested explicitly. Nevertheless, we found that in exceptional situations, like during the recent financial crisis, non-model-based information that is introduced through the projected paths for the foreign variables can improve the forecast performance. The difference in forecast performance between the different model variants, however, remains small at horizons of up to one year.

Thus, in contrast to the conjecture of Dennis and Lopez (2004a, b), we found that a GVAR model is able to produce reasonable forecasts even if one is interested in a single economy that forms a part of a global system. Moreover, the forecasting performance of the GVAR is likely to benefit further from Bayesian methods of estimation or forecast averaging over different model specifications and estimation windows (see Pesaran, et al., 2009). Another way to improve forecast precision would be to consider different country sets to determine those economies that exert the largest impact on the domestic variables (see Assenmacher-Wesche and Geismann, 2012).

In sum, we find that the GVAR achieves a similar forecast performance to alternative models. Thus the conjecture that such a model is not suited for applied purposes appears unfounded.

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17

Regional financial spillovers across Europe

Alessandro Galesi and Silvia Sgherri

17.1 Introduction

Financial systems in advanced and emerging economies of Europe have undergone remarkable changes over the past decade. Cross-border ownership of assets has increased, revealing important benefits, but also new risks associated with financial integration. Greater financial integration has clearly shown its ability to disperse claims to a broader range of portfolios, so that risks are better spread. In particular, financial integration holds great potential to smooth incomes through cross-border asset diversification, and thus stabilize income in the face of asymmetric shocks.[1] Adjusting well to shocks means having a system that is not only resilient but also reallocates resources more efficiently across sectors and across firms, thereby fostering growth.[2] At the same time, though, financial integration poses new challenges to market investors and policymakers. Cross-border ownership of assets exposes financial institutions such as banks to macroeconomic, financial, and asset price fluctuations in the countries where they hold positions. Increasingly complex linkages across market segments and borders make the transmission of shocks in the international economy and the pattern of risk dispersion more opaque, creating uncertainty for agents and policymakers about where the ultimate risks lie.

The sizable cross-border financial linkages across Europe highlight the vulnerabilities arising from reliance on concentrated foreign funding. Indeed,

[1] Empirical analysis shows that, since 1999, risk sharing has begun to emerge across European economies, although the extent to which financial integration is able to insure incomes against country-specific shocks is still limited and uneven across regions (IMF, 2008).

[2] Empirical studies find that advances in financial integration are indeed associated with better growth opportunities and that Europe is one of the world regions that has integrated the fastest, reaping the largest real gains in the process (De Nicolò and Ivaschenko, 2008).

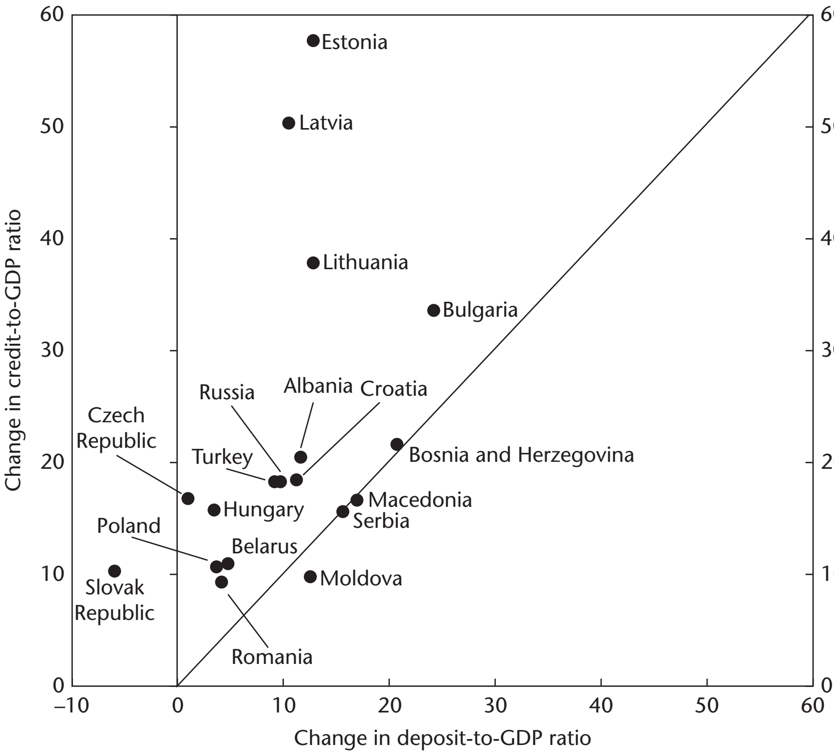

Figure 17.1. Increasing reliance of emerging Europe on foreign bank funding. Change in deposit and credit to GDP, 2003–2007, in percentage points.
IMF, *International Financial Statistics*; and IMF staff calculations.

over the period between 2003 and 2007, credit growth in most countries in the region—particularly in the Baltic countries—has significantly outpaced deposit growth (Figure 17.1).

Consolidated foreign claims of reporting banks on individual countries from international banking statistics can also provide an idea of the size and allocation of exposures of emerging European countries to western European economies, on the basis of the nationality of the reporting banks.[3] Data

[3] The Bank for International Settlements (BIS) consolidated banking statistics report banking groups' on-balance sheet financial claims on the rest of the world and thereby provide a measure of the risk exposures of lenders' national banking systems. The quarterly data cover contractual lending by the head office and all its branches and subsidiaries on a worldwide consolidated basis, e.g. net of inter-office accounts. Reporting on this contractual lending on an immediate borrower basis allows the allocation of claims to the bank entity that would bear the losses as a result of default by borrowers. Total claims are broken down by maturity, sector (banks, non-bank private sector, and public sector) as well as vis-à-vis country. Currently, central banks in 30 countries report their aggregate national consolidated data to the BIS, which uses them as the basis for calculating and publishing global data. The data are published as part of the BIS

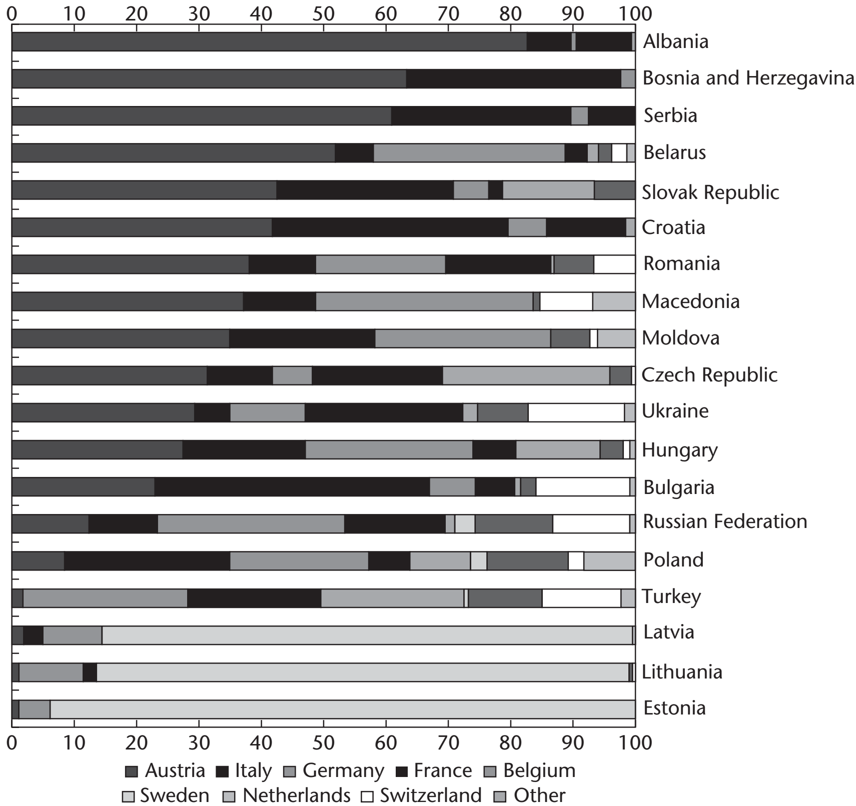

Figure 17.2. Concentration of emerging Europe exposure to western Europe.

Data for June 2007, in percentage points. Emerging Europe exposure to western European banks is defined as the share of the reporting banks in each western European country in the total outstanding claims on a given emerging European country (both bank and non-bank sectors). For example, about 42% of Croatia's exposures to western European reporting banks is owed to Austrian banks, 38% to Italian banks, 13% to French banks, etc. For the Baltic countries, 85% or more of exposures to the reporting banks is owed to Swedish banks. Source: Bank for International Settlements, *Quarterly Review*, December 2007.

suggest, for example, that most emerging European economies are heavily exposed to—and dependent on—western European banks (either directly or through the local banking systems), with concentrated exposures to banks in Austria, Italy, and Germany, and the Baltic countries have large exposures to Sweden (Figure 17.2).[4]

In order to shed light on potential international spillovers and the feedback between the real and the financial sectors, it is crucial to look into

Quarterly Review. For detailed information about the structure of the BIS consolidated banking statistics, see McGuire and Wooldridge (2005).

[4] For more details on these issues, see Arvai et al. (2009).

the time profile of the cross-country transmission of financial shocks, while explicitly accounting for regional interdependencies. In this perspective, country-specific vector error-correction models are estimated, where the domestic macroeconomic variables are related to the corresponding foreign variables constructed to match the international financial flows of the country under consideration. The individual country models are then combined consistently and cohesively to generate predictions for all the variables in the world economy simultaneously.

17.2 The GVAR model

In order to assess the importance of financial spillovers among countries, we build a GVAR model, following Pesaran, Schuermann, and Weiner (2004, henceforth PSW) and Dées, di Mauro, Pesaran, and Smith (2007, henceforth DdPS). Our GVAR model is estimated for 26 European countries, grouped into five regions plus the US using monthly data from June 1999 to April 2008.[5] Countries and regions included in the analysis are listed in Table 17.1.

The domestic variables included in the country-specific models are the following: the real interbank rate (*ibk*) and the rates of growth of, respectively,

Table 17.1. Countries and regions in the GVAR model.

US	Euro area	Other developed European countries
	Austria	Denmark
	Belgium	Norway
	Finland	Sweden
	France	Switzerland
	Germany	United Kingdom
	Greece	
	Ireland	
	Italy	
	Netherlands	
	Portugal	
	Slovenia	
	Spain	
South-eastern European countries	**Central-eastern European countries**	**Baltic countries**
Bulgaria	Czech Republic	Estonia
Croatia	Hungary	Latvia
	Poland	Lithuania
	Slovak Republic	

[5] Therefore the US is the only non-European economy in our GVAR.

real credit to corporates (*gcc*), real equity prices (*gequ*), and real gross domestic product (*ggdp*). Specifically, these variables are constructed as follows:

$$
\begin{aligned}
gequ_{it} &= \ln(EQU_{it}/EQU_{i,t-12}) \times 100 - \ln(CPI_{it}/CPI_{i,t-12}) \times 100,\\
gcc_{it} &= \ln(CC_{it}/CC_{i,t-12}) \times 100 - \ln(CPI_{it}/CPI_{i,t-12}) \times 100,\\
ggdp_{it} &= \ln(GDP_{it}/GDP_{i,t-12}) \times 100 - \ln(CPI_{it}/CPI_{i,t-12}) \times 100,\\
ibk_{it} &= IBK_{it} - \ln(CPI_{it}/CPI_{i,t-12}) \times 100,
\end{aligned}
$$

where EQU_{it} is the nominal equity prices index, CC_{it} the nominal credit to corporations, CPI_{it} the consumer price index, GDP_{it} the nominal gross domestic product, and IBK_{it} is the nominal interbank rate, for country i over the period t.[6]

Country-specific foreign variables are constructed using financial weights, mirroring the relative importance of each country's financial partner. In particular, weights are computed using cross-country bank lending exposures data for the period 1999–2007. Financial weights represent an original contribution to the GVAR modeling technique. In fact, PSW (2004) and DdPS (2007) employ weights based on cross-country trade flows, Vansteenkiste (2007) uses weights based on the geographical distances among regions, whereas Hiebert and Vansteenkiste (2007) adopt weights based on sectorial input–output tables across industries.

Given that most of the variables under study have a unit root, we individually estimate each country model in its vector error-correcting form. Following the methodology explained in Chapter 2, we treat the foreign variables as weakly exogenous, in order to ensure consistency of the parameter estimates.[7] Moreover, we construct the GVAR model after having estimated each country model. All country models contain the four domestic variables and their corresponding foreign-specific counterparts, while no global variables are considered. Hence, our GVAR model includes in total 108 (27×4) endogenous variables.

[6] Monthly data for credit growth in the corporate sector have been provided by national central banks; equity prices are taken from Bloomberg, while three-month interbank interest rates and consumer price indices have been collected from the IMF International Financial Statistics. Quarterly data on GDP growth have been exponentially interpolated to derive corresponding series with monthly frequency. When not previously performed, the series are seasonally adjusted using the Census X12 procedure.

[7] We investigate the order of integration of each variable under study by means of formal unit root tests, namely the traditional augmented Dickey–Fuller (ADF) and the weighted symmetric DF test of Park and Fuller (1995). The tests indicate that the hypothesis of a unit root cannot be rejected for most variables in most countries. Weak exogeneity tests of Johansen (1992) and Harbo et al. (1998) show that the weak exogeneity assumption is not rejected for most of the foreign variables. Detailed results can be found in Galesi and Sgherri (2009).

17.3 Assessing regional financial spillovers

In our application, we analyse the dynamic properties of our GVAR model by simulating a negative standard-error shock to the US growth rate of real equity prices. The scope of this simulation is to determine the degree of financial spillovers across European subregions: in other words, we seek to analyse how each region responds to the shock. Since each economy is linked to the others, each country/region will be affected by the disturbance.

We undertake the dynamic analysis of the GVAR model by means of generalized impulse response functions (GIRFs), as proposed by Koop, Pesaran, and Potter (1996) for nonlinear models and further developed in Pesaran and Shin (1998). This approach does not orthogonalize the residuals of the system, as it takes into account the historical correlations among the variables, summarized by the estimated variance–covariance matrix. On one hand, since shocks are not identified, the GIRFs cannot provide information about the causal relationships among the variables. On the other hand, GIRFs do not require any a priori economic-based restrictions and they are invariant to the ordering of the variables in the model. With this in mind, GIRFs can provide interesting insights on how shocks propagate internationally, by unveiling potential linkages among different national economies. Then, by means of the generalized forecast error-variance decomposition (GFEVD) we investigate the international financial linkages across the regions. In doing so, we allocate the forecast error variance of the simulated historical shock into its respective variables and regions. The relative contributions measure the importance of the innovation to a given region's variable to the rest of the regions' variables. The sum of these contributions does not add up to unity, due to the existence of contemporaneous correlations among innovations. Although the contributions of each region to the forecast error variance of the historical shock cannot be considered as proportions, GFEVD remains a useful device to study the transmission channels through which region-specific shocks are geographically propagated.[8]

17.3.1 *Generalized impulse response functions*

The GIRFs associated to a one-standard-error negative shock to the US growth rate of real equity prices—equivalent to a 2.86% drop—are plotted in Figure 17.3. For each region, the charts show the dynamic response of each variable over a time horizon of two years, which is a reasonable period for inference on short-run macroeconomic dynamics.

[8] Regional impulse responses and forecast error variances are obtained as weighted averages of the counterparts at country level. Aggregation weights are based on averages of purchasing power parity GDPs of all countries under study, for the period 1999–2008.

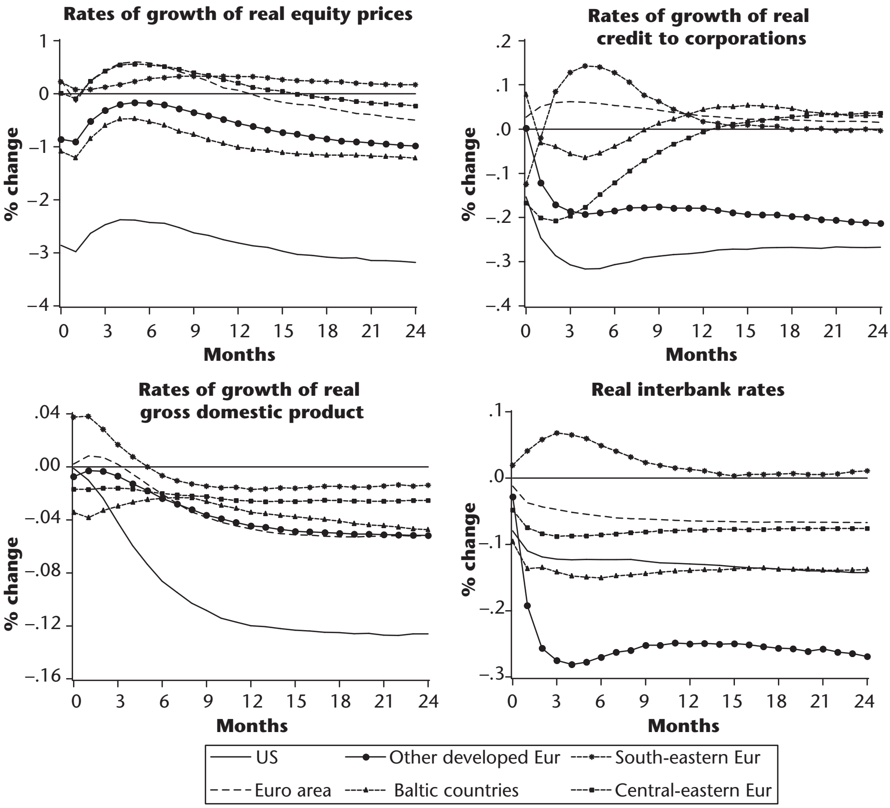

Figure 17.3. Generalized impulse responses of a negative (–1 σ) shock to US rates of growth of real equity prices.

The top-left graph plots the regional GIRFs associated with the growth rates of real equity prices. Following an instantaneous fall, real equity prices in the US partially recover after four months (to a 2.37% decrease), to then fall by 3.17% below the baseline after two years. The other regions' GIRFs generally display synchronized dynamics with the US: the considerable extent to which regional GIRFs follow the US dynamic response suggests that these countries' equity markets are strongly interrelated. This is particularly true for those countries characterized by mature financial systems. As expected, the dynamic behaviour of the GIRF associated with south-eastern European countries is mainly self-driven, implying a low degree of financial integration of these countries with respect to the rest of the world.

The top right graph shows a lack of synchronization among the growth rates of real credit to corporations of the regions under analysis. The response for the US shows, on impact, a 0.15% decline, further reaching a minimum of 0.32% below the pre-shock level after four months. After two years, the effect averages a 0.27% decrease with respect to the baseline. The GIRF for the other developed European countries share a common behaviour with the US: it starts on impact from the zero line, rapidly falling 0.2% below it, and stabilizing over time around that level. The behaviour of the GIRFs related to the Baltic countries and the central-eastern European countries are similar: they decrease in the short run, while returning over time to their initial levels. Surprisingly, the Euro area's credit growth rate hardly increases above its pre-shock level. Finally, the GIRF associated with the south-eastern European countries fluctuates considerably: it increases during the initial months, reaching its peak after four months (0.14% increase), and implying a complete reabsorption of the shock after two years. This implies that the responses of credit growth are mainly region-specific, hardly affected by common international dynamics.

The bottom left graph displays regional GIRFs associated with the real GDP growth rates. We observe a general decrease in GIRFs across all the regions, and their dynamic behaviour appears to be moderately correlated. The strongest response is observed for the US: the associated GIRF monotonically decreases over time and stabilizes after two years to 0.13% below the pre-shock level. Similar behaviour is found for the GIRFs associated with the euro area and the other developed European countries: their GIRFs mildly decrease over time, both reaching levels averaging 0.05% below the zero line. The responses associated with the other regions behave differently during the first months after the shock, although they stabilize below baseline after two years. These findings suggest that there exists considerable international co-movement of real growth among regions. Finally, the bottom right graph shows the responses associated with the real interbank rates. Also in this case, the majority of the GIRFs decreases over time. The US real interbank rate decreases on impact by 8 basis points; it then falls steadily, averaging 14 basis points below baseline after two years. The real interbank rate associated with the other developed European countries overreacts: it reaches its minimum after four months (28 basis points decrease), further stabilizing over time around a 27 basis-point loss. The GIRF of the south-eastern European countries diverges from the dynamics of the other regions: it increases, reaching a 7-basis-point increase after three months, to return to the zero line after 15 months. This suggests that fluctuations in south-eastern European countries' interbank markets are mainly idiosyncratic.

17.3.2 *Generalized forecast error variance decomposition*

Results of the generalized forecast error-variance decomposition are reported in Table 17.2. Following the historical shock to the US growth rate of real equity prices, we observe that, among the US variables, the real equity prices explain most of the forecast error variance in the short run: on impact, they contribute to 42.43% of the variance of the historical shock, while the other variables—real credit to corporations, real interbank rate, and real GDP—contribute respectively for 7.24, 6.11, and 0.05%, respectively. However, the relative contribution of real equity prices decreases over time, while the opposite holds true for the other US variables. Hence, as a first result, we observe that among the US variables, the variable that explains most of the variance of the shock in the short-term is the real equity prices growth. On the contrary, in the longer term, the other domestic variables gain increasing relevance.

From a global perspective, we generally observe the same dynamic behavior just highlighted in the US: for all other regions, real equity price growth explains most of the forecast error variance of the historical shock over the short run; its relative importance decreases over time, while the opposite is observed for the rest of the variables. After two years, real credit growth, real GDP growth, and real interbank rate explain most of the variance of the shock, and the order of importance of these three variables is generally specific to each region. Moreover, by focusing on the relative contribution of each region to the explanation of the forecast error variance, we observe the degree to which interregional linkages matter in the geographical transmission of the US financial shock. On impact, the foreign regions that contribute mostly to the variance of the shock are, in decreasing order, the other developed European countries (11.26%) and the Baltic countries (10.23%). Regional contributions change over time and, after two years, the other developed European countries explain most of the shock (15.72%), followed by the euro area (13.62%). Finally, we disentangle the contributions due to both domestic (US variables) and foreign (non-US variables) innovations. On impact, the US explains most of the variance of the shock in the short run (55.83%), but its importance decreases over time. Interestingly, in the longer term, the forecast error variance of the historical shock is mainly explained by foreign variables (53.12%).

17.4 Concluding remarks

Greater financial integration and the increasing prevalence of cross-border ownership of assets are found to be associated with better growth opportunities, with the link stronger in countries where integration is faster. At the same time, though, these developments in international financial markets have the potential to further amplify business-cycle fluctuations and the impact of asset price movements on real activity by increasing the strength

Table 17.2. Generalized forecast error-variance decompositions: a negative standard-error unit shock to rate of growth of US real equity prices.

Months		0	1	2	4	8	12	24
US variables								
US	gequ	42.43	35.64	29.65	20.98	12.74	9.66	7.12
	gcc	7.24	9.28	11.18	13.85	15.66	15.82	15.21
	ggdp	0.05	0.07	0.45	2.50	8.39	12.67	17.38
	ibk	6.11	6.67	7.20	7.73	7.65	7.38	7.17
	US Vars	**55.83**	**51.67**	**48.48**	**45.06**	**44.45**	**45.53**	**46.88**
European variables								
Euro area	gequ	4.49	3.45	2.76	1.90	1.16	0.86	0.61
	gcc	2.08	2.54	3.17	3.77	3.40	2.96	2.42
	ggdp	1.24	1.16	1.04	0.86	1.32	2.19	3.86
	ibk	1.67	2.51	3.23	4.32	5.52	6.13	6.73
	EA Vars	9.47	9.66	10.21	10.84	11.40	12.13	13.62
Other developed European countries	gequ	6.87	6.19	4.92	3.01	1.43	0.96	0.78
	gcc	0.29	1.74	3.01	4.58	5.19	4.90	4.24
	ggdp	0.99	0.75	0.74	1.03	1.90	2.54	3.30
	ibk	3.12	6.35	8.40	10.11	9.73	8.74	7.40
	OTH Vars	11.26	15.03	17.07	18.73	18.25	17.14	15.72
Baltic countries	gequ	2.87	2.74	2.47	2.08	1.76	1.59	1.54
	gcc	1.93	1.32	1.06	0.78	0.56	0.48	0.44
	ggdp	2.14	1.98	1.99	2.07	1.95	1.74	1.46
	ibk	3.29	4.89	5.91	7.35	8.20	7.58	5.80
	BALT Vars	10.23	10.93	11.43	12.28	12.47	11.38	9.23
South-eastern Europe	gequ	1.29	0.96	0.83	0.73	0.75	0.87	1.04
	gcc	0.30	0.29	0.32	0.35	0.27	0.19	0.09
	ggdp	1.48	1.26	1.06	0.76	0.58	0.54	0.46
	ibk	0.26	0.37	0.45	0.49	0.36	0.25	0.15
	SEE Vars	3.34	2.89	2.66	2.34	1.96	1.84	1.75
Central-eastern Europe	gequ	1.39	1.24	1.16	1.06	0.92	0.84	0.86
	gcc	2.79	2.95	3.22	3.69	4.27	4.63	5.10
	ggdp	2.22	2.33	2.35	2.33	2.59	2.98	3.68
	ibk	3.46	3.30	3.43	3.67	3.70	3.54	3.17
	CEE Vars	9.86	9.82	10.15	10.76	11.47	11.98	12.81
	European Vars	**44.17**	**48.33**	**51.52**	**54.94**	**55.55**	**54.47**	**53.12**
	Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Note: Percentage of the *k*-step ahead forecast error variance of the historical shock to the United States rate of growth of real equity prices. Percentages do not sum to 100 due to non-zero covariance between the shocks; however, for better readability, we rescale variance decomposition as suggested by Wang (2002).

of cross-border financial spillovers. In particular, the sizable cross-border financial linkages across Europe highlight the vulnerabilities arising from reliance on concentrated foreign funding. International banking statistics suggest that most emerging European economies are heavily exposed to—and dependent on—western European and US banks (either directly or through the local borrowing systems).

In order to bridge the gap between purely statistical analysis and the traditional modelling approaches, in this chapter we studied the transmission of a historical negative shock to the US equity prices to advanced and emerging European countries using a GVAR model. Such a global modelling framework is able to generate forecasts for a core set of macroeconomic and financial factors related to the US and five European regions, explicitly allowing for cross-regional interdependencies in a consistent manner. Unlike other GVAR models, this chapter originally links each country to the rest of the world economy by employing cross-country financial flows from international banking statistics, e.g. annual bank lending exposures over the period 1999–2007.

From a policy analysis perspective, a number of interesting results emerge. The simulations clearly show that financial shocks are transmitted relatively quickly and often get amplified as they travel from the US to Europe. Equity markets seem to be far more synchronous as compared to the banking systems. In addition, dynamic analysis indicates that asset prices are the main channel through which, in the short run, financial shocks are transmitted internationally. Other variables—including the cost and quantity of credit—start playing a significant role in the transmission of shocks only over longer horizons.

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Conclusion

The GVAR modelling approach was developed to address the problem of interdependence across different countries in the global economy. It was advanced as a modelling response to increasing trade and financial linkages in the world economy and the concern that economic or financial crisis in one part of the world could rapidly transmit to other economies and markets, possibly accentuating the effects of the original shocks. The GVAR approach provided a timely econometric tool to model such interdependencies for policy analysis, risk management, and forecasting. It represented a natural extension of the co-integration and error-correction literature to a multi-country set up. The pioneering co-integration techniques developed by Granger and Johansen could only be applied to VAR models containing at most 6–8 variables. To construct a coherent multi-country global model, it was clear that the curse of dimensionality had to be overcome. This was done in the GVAR framework by separately estimating conditional co-integrating models for the individual economies and then combining them simultaneously for forecasting and policy analysis.

The chapters in this volume show the extent to which the GVAR approach has been adopted in the literature, developed and adapted further to answer a variety of new policy-relevant questions. Some of the main findings of these studies are summarized below for your convenience.

- In considering the drivers of inflationary pressures, external factors, such as international energy and food prices, play a key role in the majority of the regions in the world economy.
- Cross-border financial spillovers are particularly important, not only during the 2007–09 crises but more generally, in transmitting financial and real shocks across the different regions.

- US credit supply shocks have strong effects on a range of real and financial variables, not only in the US but also in many other economies, particularly those with relatively developed financial institutions.
- Double-averaged GVAR forecasts (that combine forecasts across different GVAR models estimated over different estimation windows) perform better than a number of benchmarks, especially for output, inflation, and real equity prices.
- Similarly, for nowcasting, GVAR results are more accurate than the commonly used ‘direct’ approach to nowcasting an aggregate variable. The GVAR’s nowcasts are, however, less accurate than those from the ‘indirect’ approach, which itself is based on a restricted GVAR model.
- Turning to finance applications, the GVAR framework is shown to be well suited to conduct policy analysis regarding the effect of changes in macroeconomic conditions on credit risk. The GVAR approach is particularly relevant in stress-testing exercises, where the possible effects of adverse shocks in one economy on the loan portfolio of large banks in other economies are under investigation.
- Using the GVAR approach, a number of important channels of interactions have been quantified between financial and fiscal policy variables in the euro area.
- It is shown that the GVAR approach can be readily adapted to allow for nonlinear dynamics. This is illustrated by the analysis of the relationship between bond spreads in the euro area and local and global fiscal factors. The nonlinear GVAR model is used to show that the fiscal stabilization package introduced by the Monti government in Italy at the end of 2011 most likely resulted in a 100-basis-point reduction in the spread of yield on Italian long-term bond over the German bund.
- Using a more traditional linear GVAR model, but including fiscal variables, it is shown that fiscal shocks tend to have significant domestic and international spillover effects on financial variables.
- Using the GVAR model it has proved relatively easy to quantify the effects of China’s emergence in the world economy. It is, for example, shown that the long-term impact of a China GDP shock on a typical Latin American economy has increased by three times since the mid-1990s. It is also shown that the higher interdependence of Latin America and the rest of the world owes more to the changed impact of China on Latin America’s trading partners than to increased direct bilateral trade linkages between China and Latin America. These findings help to explain why Latin America did so well during the

recent global crisis, but also point to the risks that Latin America is likely to face in the future should China's economic growth decelerate significantly.

- Applications of the GVAR to regional problems have also provided valuable insights into the transmission of shocks across regions within a given economy, with important lessons for regional policy. The GVAR model developed for the West African Economic and Monetary Union (UEMOA) economies points to a high degree of heterogeneity in response to shocks across the member countries, which is an important consideration in measuring the costs of union membership for each country.
- In an application to the euro area, simulating the effects of shocks to competitiveness, a decrease in wages leads to some short-term improvement in current accounts. At the same time, however, the simulation results make it clear that to obtain significant effects the wage shock would have to be quite large.
- In the case of many small, open economies, the GVAR model need not be very large to be useful in forecasting or policy analysis. For example, in the case of the Swiss economy an adequate GVAR model can be constructed by including US, German, and French economies, and aggregating the rest of the world into a fourth 'foreign' economy. Forecasts based on such GVAR model perform better than a number of benchmark forecasts.
- Finally, in a model including US and European countries, asset prices are the main channel through which financial shocks in the short run are transmitted internationally. The contribution of other variables, such as the cost and volume of credit, becomes more important only over longer horizons.

The way forward

As anticipated by some of the contributions in this volume, we are likely to see a closer integration between the GVAR and the economic-theory based macromodels such as DSGE or new-Keynesian country-specific models.

Currently, the country-specific models in the GVAR focus only on a number of key core variables. These models can be augmented with satellite models that deal with labour market, investment, and consumption decisions. The satellite, or submodels, can be developed conditional on the core variables of the GVAR. Such extensions allow a better understanding of the domestic economy interlinkages that are in turn related to the global economy through the GVAR country networks.

We would also expect further GVAR applications that use firm-level data, both for the analysis of business cycles as well as for macroprudential purposes.

We are likely to see further uses of the GVAR in forecasting, at both national and regional levels. GVAR, being a closed system, is particularly suited to generating internally consistent forecasts and its forecast performance can be enhanced if the estimation of country-specific models is regularized by application of shrinkage or Bayesian techniques when estimating the country models.

Amongst new policy applications of the GVAR, the analysis of economy–environment, globalization, and inequality, and cross-country migration and labour market developments could be of particular importance.

The experience so far has also taught us that several developments and applications of the GVAR at times have come as a surprise, simple fruits of the ingenuity of individual researchers. It is perhaps reasonable to predict that this is also going to be the case in the future.

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References such as '178–9' indicate (not necessarily continuous) discussion of a topic across a range of pages. Wherever possible in the case of topics with many references, these have been divided into sub-topics and/or only the most significant discussions of the topic are listed. Because the entire volume is about 'GVAR', the use of this term (and certain others which occur throughout) as entry points has been minimized. Information will be found under the corresponding detailed topics.

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