Chapter 3: Global Recessions and Output Interdependencies in a GVAR Model of Actual and Expected Output in the G7*

by

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Abstract

The performance of the world's economies are closely tied through trade and international capital markets and it is widely recognised that business cycle fluctuations in one country are quickly transmitted to others. However, there is no clear consensus on how to characterise global recessions or investigate the extent to which these are driven by the interdependencies in output determination across countries. This paper explores different facets of the recessionary experiences of 2008-11 using a GVAR representation of the actual and expected output series in the G7 economies. The nature of the interdependence of the G7 countries' economic performance is investigated and recession is considered by calculating the likelihood of a range of recessionary events defined at the national and G7-wide levels.

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1 Introduction

It is well understood that the performance of the world's economies are 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 (2011) 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 synchronised across countries compared to those that are more localised. The synchronised 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 characterisations. 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 paper is in the same vein as these recent papers estimating separate country-models using starred variables and organising 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 summarise 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 characterisation 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 investigate 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 paper, however, we focus on a very short-term horizon event, using the model to assess whether the G7 economies are in re-

[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.

cession 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 characterising the international output data movements and in obtaining good forecasting performance for different types of recessionary events.

2 Modelling Output in a Global Economy

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 macro relationships 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 which 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 upto h quarters, say, can replicate the dynamics of a structural VAR model involving h macro variables 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 summarise 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 characterise business cycles and recession.

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 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 emphasises the

[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.

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 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 emphasised 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

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

for $t = 1, ..., T$ 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.

[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.

The model is best estimated in the form in (1) but it can be written in levels form as

$$\mathbf{z}_t = \mathbf{A}_0 + \sum_{s=1}^{p+1} \mathbf{A}_s \mathbf{z}_{t-s} + \boldsymbol{\varepsilon}_t, \qquad t = 1, ..., T, \tag{2}$$

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 (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 ($t = T+1, ..., T+h$), 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 $\mathbf{Z}_{T+1,T+h} = \{\mathbf{z}_T, \mathbf{z}_{T+1}, ..., \mathbf{z}_{T+h}\}$ given the observed data $\mathbf{Z}_{1,T} = \{\mathbf{z}_1, \mathbf{z}_2, ..., \mathbf{z}_T\}$ 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 $t = 1, .., p+2$ and simulating data for $t = p+3, .., T$) each of which can be used to estimate an alternative version of (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, ${}_{T+1}y_T, {}_{T+2}y_{T+1}, {}_{T+3}y_{T+2}, ...$ can be written as $R(\mathbf{Z}_{T+1,T+h})$ so that the probability that the event occurs is

$$\text{probability of recession} = \int_R \Pr(\mathbf{Z}_{T+1,T+h} | \mathbf{Z}_{1,T}) \;\; \partial \mathbf{Z}_{T+1,T+h}. \tag{3}$$

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 $\nu(\omega, R(\mathbf{Z}_{T+1,T+h}))$ depends on the outcome of a choice variable ω and

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

the occurrence of the recessionary event, the decision-maker's problem can be written as

$$\max_{\omega}\left\{ \int \nu(\omega, R(\mathbf{Z}_{T+1,T+h}))\Pr\left(\mathbf{Z}_{T+1,H} \mid \mathbf{Z}_T\right) \; d\mathbf{Z}_{T+1,T+h} \right\}. \tag{4}$$

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, maximises the value of the objective function.

The expressions in (3) and (4) emphasise 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.

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 (2) can accommodate the presence of unobserved global factors $\mathbf{f}_t$ by writing

$$\mathbf{z}_{it} = \mathbf{A}_{i0} + \sum_{s=1}^{p+1} \mathbf{A}_{is}\mathbf{z}_{i,t-s} + \mathbf{A}_{if}\mathbf{f}_t + \boldsymbol{\varepsilon}_{it}, \qquad i = 1, ..., n \quad \text{and} \quad t = 1, ..., T, \tag{5}$$

where $\boldsymbol{\varepsilon}_{it}$ now represent country-specific innovations. Assuming this relationship holds for all countries $i = 1, .., n$, 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 (5). In this

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

case, the unobservable common factor can be reasonably proxied by the observable vector $(1, \mathbf{z}_t^{*\prime}, \mathbf{z}_{t-1}^{*\prime},..., \mathbf{z}_{t-p+1}^{*\prime})'$ and the national model in (2) can be written

$$\mathbf{z}_{it} = \mathbf{B}_{i0} + \sum_{s=1}^{p+1} \mathbf{B}_{is}\mathbf{z}_{i,t-s} + \sum_{s=0}^{p+1} \mathbf{B}_{is}^{*}\mathbf{z}_{t-s}^{*} + \mathbf{v}_{it}, \qquad i = 1, ..., n \quad \text{and} \quad t = 1, ..., T. \tag{6}$$

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 (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 (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 stack the country-specific series into a single vector $\mathbf{z}_t = (\mathbf{z}_{1t}',..,\mathbf{z}_{nt}')'$ 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 (6) can be stacked to write

$$\mathbf{z}_t = \mathbf{B}_0 + \sum_{s=1}^{p+1} \mathbf{B}_s\mathbf{z}_{t-s} + \sum_{s=0}^{p+1} \mathbf{B}_s^*\mathbf{W}\mathbf{z}_{t-s} + \mathbf{v}_t, \qquad t = 1, ..., T, \tag{7}$$

and so

$$\mathbf{z}_t = (\mathbf{I} - \mathbf{B}_0^*\mathbf{W})^{-1} \left(\mathbf{B}_0 + \sum_{s=1}^{p+1} (\mathbf{B}_s + \mathbf{B}_s^*\mathbf{W})\mathbf{z}_{t-s} + \mathbf{v}_t \right), \qquad t = 1, ..., T, \tag{8}$$

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

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, United Kingdom, and United States) 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 mid-way 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 ${}_ty^c_{it} - {}_ty^c_{i,t-4}$ 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 ${}_ty^c_{i,t+1} - {}_t y^c_{i,t-3}$).[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, 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 ${}_ty_{i,t-1}$ is taken to be the same as the final vintage ${}_Ty_{i,t-1}$ assuming

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

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

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

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 ${}_ty^e_{it} = {}_ty^c_{it} - {}_ty^c_{i,t-4} + {}_Ty_{i,t-4}$. 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 upto one quarter previously and that it is their expectations of growth in the true output series that is reported in the surveys.

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, ${}_{t+1}y_{it} - {}_ty^e_{it}$ (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 (1) is appropriate.

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

[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.

The table 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 then, 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 ${}_ty^e_{it} -_t y_{i,t-1}$ and ${}_ty^e_{i,t+1} -_t y^e_{it}$ (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 ${}_ty^{e*}_{it} -_t y^*_{i,t-1}$ and ${}_ty^{e*}_{i,t+1} -_t y^{e*}_{it}$ (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 characterised 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 fourteen 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.

3.2 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 (5)-(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 seventy observations in our sample $1994q1-2011q2$, 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 nineties 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 (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 maximise 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]

3.2.1 Country-specific events: national recession

Figure 1.1-1.7 plots 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 (1) for each country, as described in Table 1, and then stacking these together as in (5)-(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 emphasising 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

[11] Of course, attention does not have to be restricted to one-step-ahead forecast 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).

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 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 summarises the degree of correspondence between 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, UK and 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.

3.2.2 G7-specific events: global recession

Finally here, Figure 2.1-2.2 provides corresponding probability forecasts of two related G7-wide events. Figure 2.1 shows the nowcast probabilities that the *average of the growth rates* across the G7 economies falls below zero. Figure 2.2 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 2008q2-2009q1, and the country count event occurring five times 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 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.

4 Concluding remarks

The 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 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 summarised 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 organised 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.

5 Bibliography

Garratt, A. and K. Lee, (2010), "Investing Under Model Uncertainty: Decision Based Evaluation of Exchange Rate Forecasts in the US, UK and Japan", *Journal of International Money and Finance*, 29, 3, 403-422.

Garratt, A., K. Lee, E. Mise and K. Shields (2008), "Real Time Representations of the Output Gap", *Review of Economics and Statistics*, 90, 4, 792-804.

Garratt, A., K. Lee, E. Mise and K. Shields (2009), "Real Time Representations of the UK Output Gap in the Presence of Model Uncertainty", *International Journal of Forecasting*, 25, 81-102.

Garratt, A., K. Lee, M.H. Pesaran and Y. Shin (2003), "Forecast Uncertainty in Macroeconometric Modelling: An Application to the UK Economy", *Journal of the American Statistical Association*, 98, 464, 829-838.

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

Garratt, A., K. Lee and K. Shields (2012), "Global Recessions and Output Interdependencies in a GVAR Model of Actiual and Expected Output in the G7", *mimeo*, University of Nottingham, April.

Harding, D. and A. Pagan, (2005), "A Suggested Framework for Classifying the Modes of Business Cycle Research", *Journal of Applied Econometrics*, 20, 2, 151-161.

International Monetary Fund, (2009), "From Recession to Recovery: How Soon and How Long?", Chapter 3 in *World Economic Outlook: Crisis and Recovery*, 103-138, April.

Lee, K., N. Olekalns, K. Shields and Z. Wang (2011), "The Australian Real-Time Database: An Overview and an Illustration of its Use in Business Cycle Analysis", *mimeo*, University of Melbourne, September.

Lee, K. and K. Shields, (2011), "Decision-Making in Hard Times: What is a Recession, Why Do We Care and When Do We Know We Are in One?", *North American Journal of Economics and Finance,* 22, 1, 43-60.

Mankiw, N.G. and M.D. Shapiro (1986): News or Noise: An Analysis of GNP Revisions, *Survey of Current Business*, 20-25.

Orphanides, A. and S. van Norden (2002), "The Unreliability of Output Gap Estimates in Real Time", *Review of Economics and Statistics*, 84, 4, 569-83.

Pesaran, M.H. (2007), "A Simple Panel Unit Root Test In The Presence Of Cross Section Dependence", *Journal of Applied Econometrics*, 22, 2, 265-312.

Pesaran, M.H. and A. Timmermann (2009) "Testing Dependence Among Serially Correlated Multicategory Variables", *Journal of the American Statistical Association*, vol 104, 485, 325-337.

Table 1: Summary Statistics for Estimated National VAR Models, $1994q1-2011q2$

	${}_{t}y_{i,t-1}-{}_{t-1}y_{i,t-2}$				${}_{t}y^{e}_{it}-{}_{t}y_{i,t-1}$				${}_{t}y^{e}_{i,t+1}-{}_{t}y^{e}_{it}$			
	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	.0068	.0065	0.66		.0043	.0061	0.59		.0074	.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	.0043	.0056	0.57		.0047	.0054	0.48		.0052	.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	.0037	.0086	0.50		.0027	.0066	0.45		.0050	.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	.0029	.0083	0.48		.0014	.0072	0.35		.0052	.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	.0020	.0110	0.34		.0022	.0105	0.22		.0033	.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
United Kingdom	.0054	.0065	0.73		.0028	.0065	0.69		.0059	.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*
United States	.0062	.0070	0.57		.0083	.0066	0.39		.0054	.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; $\overline{R}^2$ is the adjusted R^2; F_1 -F_4 tests insignificance of various combinations of variables See text for details

Table 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	.900	.593	7.867**	4.448**	.933	.712	14.619**	11.617**
France	.833	.222	1.074	0.123	.867	.423	5.116**	0.000
Germany	.767	.148	0.326	0.570	.800	.346	2.429	0.611
Italy	.767	.519	4.190	0.086	.800	.540	7.034**	1.545
Japan	.633	.143	0.133	0.034	.667	.280	1.250	0.467
United Kingdom	.833	.542	7.472**	1.071	.900	.885	14.583**	7.427**
United States	.867	.556	5.729**	0.997	.900	.673	10.848**	4.874*

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).

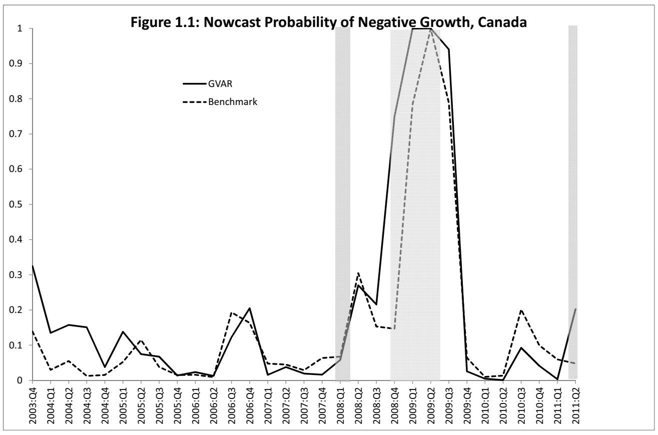

Figure 1.1: Nowcast Probability of Negative Growth, Canada

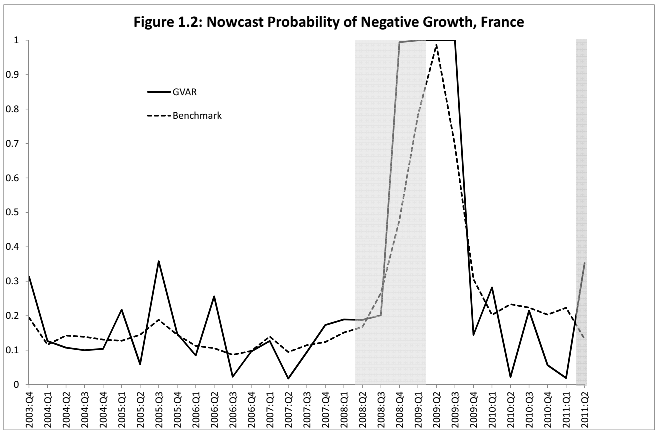

Figure 1.2: Nowcast Probability of Negative Growth, France

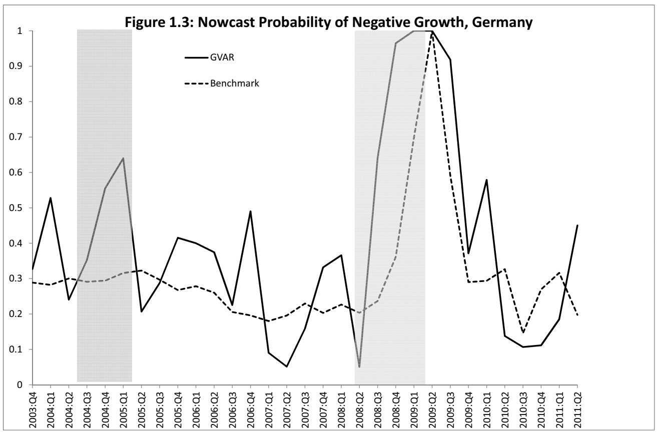

Figure 1.3: Nowcast Probability of Negative Growth, Germany

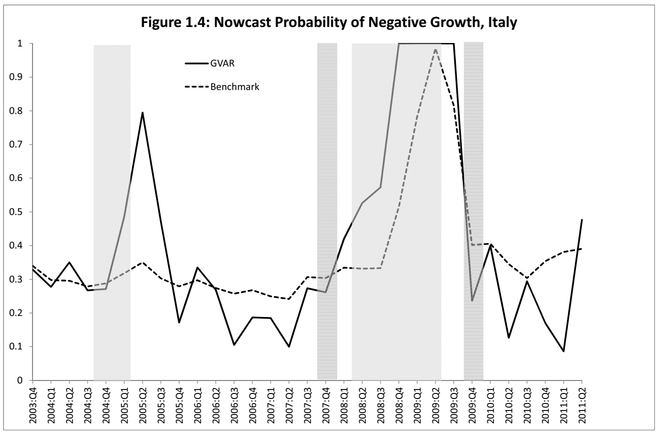

Figure 1.4: Nowcast Probability of Negative Growth, Italy

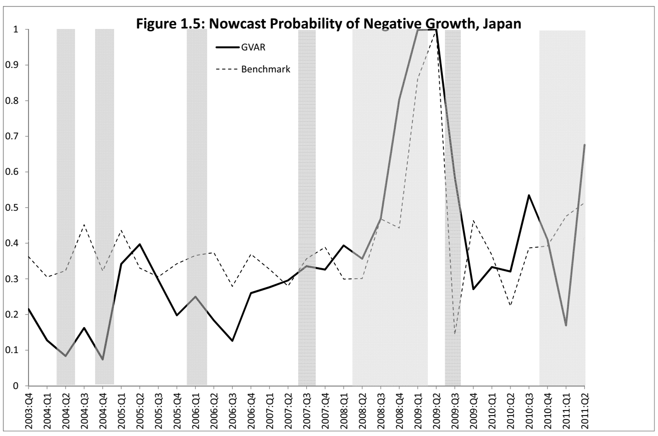

Figure 1.5: Nowcast Probability of Negative Growth, Japan

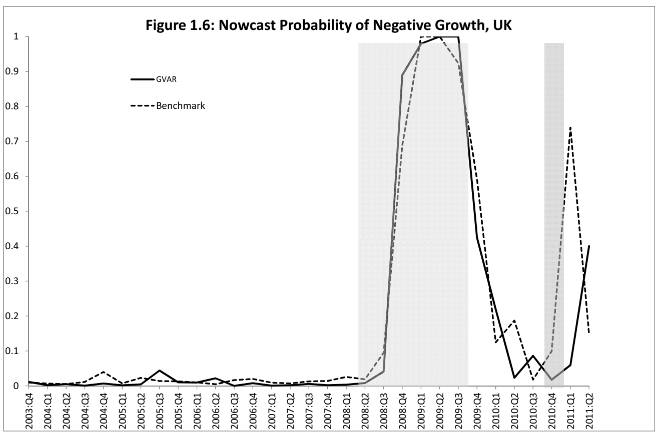

Figure 1.6: Nowcast Probability of Negative Growth, UK

Figure 1.7: Nowcast Probability of Negative Growth, US

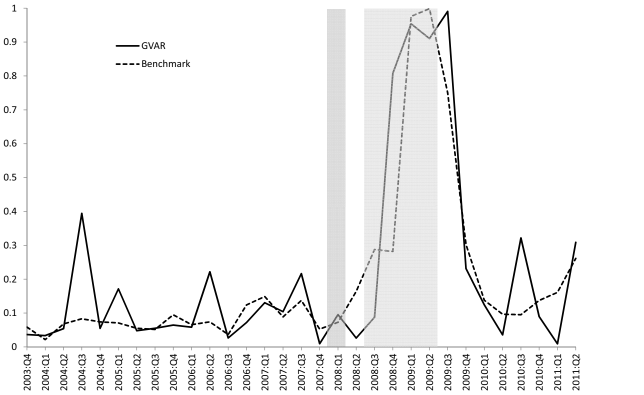

Figure 2.1: Nowcast Probability of Negative Growth, G7 Country Average

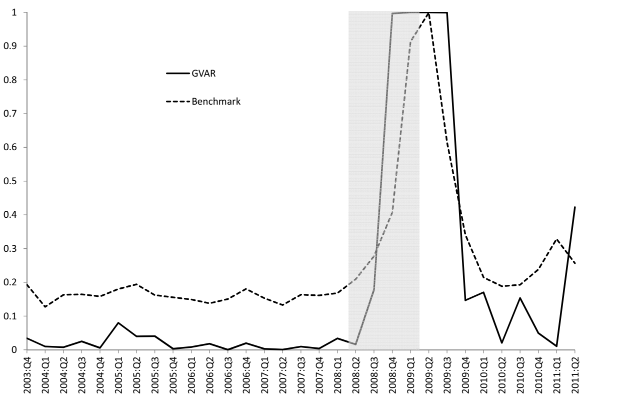

Figure 2.2: Nowcast Probability of Negative Growth, G7 Country Count