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Hugo Gerard

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Economic Research Department
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Author: gerardh at domain rba.gov.au

Media Office: rbainfo@rba.gov.au

Abstract

Inflation rates across countries tend to exhibit a degree of co-movement. In this paper we use a panel vector autoregression (panel VAR) model to investigate possible explanations of this co-movement for the G7 economies. Shocks to commodity prices are found to be more important than common movements in real activity as a driver of 'global inflation' dynamics. However, commodity prices and common real activity cannot explain all of the co-movement in inflation. Even when controlling for these factors, a common indicator of inflation still offers explanatory power for domestic inflation in the panel VAR. Given the role of global inflation in explaining inflation in the G7 countries, we then consider the significance of global inflation for Australian inflation. We find that movements in international inflation offer useful information when included in models of Australian inflation, particularly headline inflation.

JEL Classification Numbers: C33, E31, E32, F44,

Keywords: global inflation, panel VAR, factor models, Bayesian estimation

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1. Introduction

Just as there is an extensive literature on the co-movement of real business cycles,[1] there is growing acknowledgement of substantial co-movement of inflation across countries. For example, Ciccarelli and Mojon (2010) found that, on average, up to 70 per cent of the variation in countries' consumer price index (CPI) inflation can be explained by a common factor. Neely and Rapach (2008) found that common and regional factors together can explain around 50 per cent of the variation in national inflation rates. Monacelli and Sala (2009) find a smaller number using disaggregated data but still, on average, around 15–30 per cent of the variation in consumer prices can be explained by a common factor.

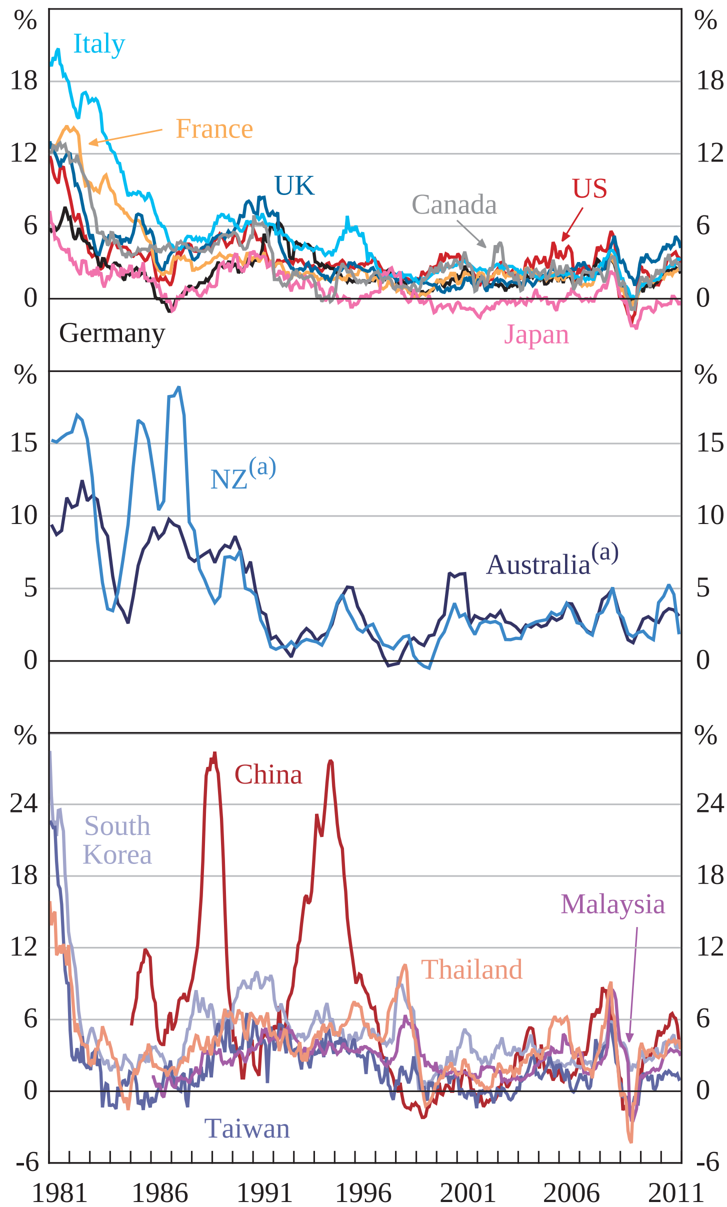
This co-movement in inflation rates can be seen in Figure 1, which plots year-ended CPI inflation for a number of economies.

Inflation rates across countries may move together for a number of reasons. Over longer periods, common changes to policy frameworks and policymakers' views about the appropriate rate of inflation can drive changes in the level of inflation, resulting in observed co-movement. In the short to medium term, if exchange rates do not adjust to offset shocks to the international prices of imported goods, these shocks can flow through to domestic consumer prices. Also, fluctuations in global output and international trade can influence domestic demand and therefore domestic inflation. Common shocks to which a number of countries are exposed (for example, an oil price shock, demand and supply shocks) could also lead to correlated movements in inflation rates.

1 See Backus, Kehoe and Kydland (1992) for the seminal contribution. Kose, Otrok and Whiteman (2003) and Canova, Ciccarelli and Ortega (2007), amongst others, have shown that a global or common component can explain a substantial share of the variation in real variables across countries. Potential drivers of this co-movement pointed to in the literature include international trade, financial conditions and the stance of monetary policy (Canova *et al* 2007), along with movements in productivity (Crucini, Kose and Otrok 2011) and consumption demand (Wen 2007).

Figure 1: International CPI Inflation

Year-ended



Notes: (a) Quarterly

Sources: ABS; CEIC; Thomson Reuters

Just how important the various channels will be, however, is likely to be influenced by structural features of different economies, such as the degree of trade integration, the flexibility of the exchange rate, and also the extent of exchange rate pass-through by domestic firms. Policy responses across countries will also be important. While an inflation-targeting central bank with an independent inflation target should determine the level of domestic inflation in the long-run, inflation rates across countries may still be observed to move together in the short to medium term due to lags in the transmission of monetary policy and the fact that certain shocks, for example, temporary shocks, may warrant only a partial or even no monetary policy response.

This paper investigates the topic of co-movement in inflation rates using a panel vector autoregression (panel VAR) model (Canova *et al* (2007) and Canova and Ciccarelli (2009)) for the G7 economies. The panel VAR framework is very flexible and has features in common with more familiar factor modelling techniques. We investigate the significance of international inflation in explaining domestic inflation in the G7 countries after controlling for potentially important explanations of the observed co-movement in the data. In particular, we include common and country-specific measures of real activity, and also oil and non-fuel commodity prices in the model.[2] The panel VAR framework is also used to investigate which of these potential explanations of 'global inflation' are most supported by the data.

Our results suggest that common shocks to commodity prices are more important for driving global inflation dynamics than are common movements in real activity. Neither of these potentially important drivers of global inflation, however, can fully explain the observed co-movement in inflation in the G7 data. Even when controlling for these factors, the common inflation indicator, constructed as a simple average of individual country inflation rates, is found to be a significant explanator of domestic inflation, suggesting that international movements in inflation contain useful information over and above what is reflected in data on foreign real activity and, to a lesser extent, commodity prices.

Given the role for global inflation in explaining G7 countries' inflation, we then turn to examine the role that global inflation plays in explaining Australian inflation. After augmenting standard single-equation models of Australian inflation with the average of G7 countries' inflation rates, we find that coincident

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2 Most other studies on global inflation have only worked with inflation data. An exception to this is Mumtaz, Simonelli and Surico (2011), who employ a dynamic factor model over a very long sample and incorporate data on both output and inflation in their estimation. They do not, however, control for commodity price movements or other measures of real activity such as consumption and investment.

information on international inflation, in particular, is a statistically significant explanator of both headline and, to a lesser extent, trimmed mean inflation.

The rest of the paper is structured as follows: Section 2 reviews the relevant literature, paying particular attention to the possible determinants of global inflation; Section 3 outlines the panel VAR model and its key features (further details of the model and the estimation procedure are in Appendix A); Section 4 presents the main results and discusses the role of correlated movements in real activity and commodity prices in driving movements in global inflation; and Section 5 discusses the significance of international inflation for modelling inflation in Australia.

2. Global Inflation

2.1 Empirical Evidence

A number of papers have found that there is statistically significant co-movement in inflation rates across countries. Ciccarelli and Mojon (2010) use a panel of 22 OECD countries' inflation rates and find that different measures of global inflation (such as a simple average, the official OECD measure, or the first principal component of the data) can explain up to 70 per cent of the movement in domestic CPI inflation rates. There are reasons to think, however, that this result represents somewhat of an upper bound on the contribution of international influences to inflation. Ciccarelli and Mojon use aggregate inflation data in year-ended terms and a long sample from 1961:Q1 to 2008:Q2 that includes large common shocks, such as the oil price shocks in the 1970s, and possible (synchronised) regime changes. Consistent with this, Ciccarelli and Mojon estimate the contribution of international influences to be closer to 30 per cent after de-trending their data to highlight business cycle frequencies.

Monacelli and Sala (2009) use monthly disaggregated (to the product level) CPI data for the United States, France, Germany and the United Kingdom over the sample 1991 to 2004 and find that between 15–30 per cent of the variation in domestic inflation can be attributed to international factors. Since Monacelli and Sala's data are both monthly and disaggregated they will tend to be noisier and so should have lower measured co-movement independent of the underlying relationships in the data. This result might then be thought of as a lower bound to the variance in domestic inflation that can be explained by 'global inflation'.

Neely and Rapach (2008), using aggregate data and a similar methodology to Kose *et al* (2003) (who study common movements in real activity), decompose national inflation rates into common, regional and idiosyncratic components. Their paper incorporates a large cross-section of 64 countries, including data from Latin America, Asia, Africa and the Middle East, along with North America and Europe, allowing them to distinguish between common and regional effects. Over the sample 1951 to 2009 they find that, on average across countries, 35 per cent of the variation in domestic inflation rates can be explained by the global factor, with a further 15 per cent explained by regional factors. Neely and Rapach also find that the North American and European regional factors have become more important since the 1980s.

Other work includes Wang and Wen (2007) who find that cross-country quarterly inflation rates (for 18 OECD countries) are highly correlated (correlation of around 0.6 on average) and more so than quarterly output growth (correlation of around 0.2 on average). Mumtaz *et al* (2011) work with a very long sample, going back as far as the 1800s for some countries, and find that the share of inflation variation due to a common factor has increased post-1985. Work by Hyvonen (2004) documents the convergence of inflation rates using a large sample of IMF member countries and the role played by inflation targeting in driving this result.

2.2 Determinants of Global Inflation

The majority of the papers highlighted above focus on the statistical result that inflation rates tend to move together across countries. There has been less work looking at the possible determinants of this observed co-movement. From an economic theory point of view, it is not necessarily obvious how developments in inflation in other countries might influence domestic inflation. In the long-run, a central bank with independent monetary policy should determine the level of domestic inflation (see, for example, Woodford (2009)). Furthermore, most structural economic models are unable to capture the phenomenon of inflation co-movement (see, for example, Cicarelli and Mojon (2008) and their discussion of the work by Clarida, Galí and Gertler (2002)). Wang and Wen (2007) show that neither a two-country New Keynesian sticky-price model nor a sticky-information model can explain the phenomenon of co-movement in inflation rates unless monetary shocks across countries are themselves correlated. They also document that inflation rates across countries tend to be more highly correlated than output, which is the opposite of what real business cycle theory would predict.

In the short to medium run, however, there are a number of reasons why inflation rates across countries could move together. Increased trade integration (or globalisation more generally) has been highlighted as a key mechanism influencing inflation rates in a number of countries (see Helbling, Jaumotte and Sommer (2006) for work done by the IMF and also Bean (2007)). For example, as east Asian economies have become more integrated into the global trade network, the declining relative price of manufactured goods has been a global phenomenon. Bernanke (2007) links increased trade integration and inflation co-movement via two channels: a direct terms of trade channel that increases or decreases import prices; and a more indirect pro-competitive effect, working to reduce the pricing power of domestic firms and lower mark-ups. Ball (2006) presents an alternate view and argues that globalisation has had no material impact on the dynamics of inflation.

One natural explanation for the correlation in inflation rates is that real activity is also correlated across countries. That is, co-movement in business cycles could lead to co-movement in inflation as domestic inflation responds to correlated changes in domestic demand. The evidence in favour of this explanation, however, is somewhat mixed. Borio and Filardo (2007) have argued that global factors are becoming an important determinant of inflation dynamics. They include a measure of global slack into standard Phillips curve type equations of domestic inflation and find it adds considerable explanatory power. Ihrig *et al* (2007), however, show that this finding is not robust to alternate specifications of the Phillips curve, nor the measure of global slack. Eickmeier and Moll (2009) estimate factor-augmented Phillips curves for 24 OECD economies and allow global forces to impact inflation indirectly through common movements in domestic demand and supply. They find that the common component to changes in unit labour costs is a significant determinant of inflation but less so the common component to the output gap. Eickmeier and Moll also find that the first principal component explains less of the variation in output gaps across countries than is the case for inflation, suggesting there are other mechanisms driving the co-movement in inflation than simply business cycle correlations.

Common shocks represent another potential driver of the co-movement in inflation. As discussed by Ciccarelli and Mojon (2008), common shocks will be more likely to generate co-movement if they account for a large share of the variance in inflation and inflation rates respond in a similar fashion across countries. Common shocks to commodity prices, therefore, would seem to be one potential explanation for the global inflation phenomenon. Commodity prices are largely determined in global markets, and so large price fluctuations can be experienced in a number of economies at the same time. Also, food and energy prices make up a substantial share of consumer consumption baskets around the world, meaning that movements in these prices could explain a large share of the variation in overall inflation. Movements in global commodity prices could also influence inflation expectations in a number of economies in a similar way, which could in turn affect realised inflation.

If there are substantial structural differences between economies, however, common shocks to commodity prices may not necessarily lead to significant co-movement in inflation rates. For example, a large positive oil price shock is likely to see inflationary pressures increase in a number of countries; directly through higher fuel costs but also indirectly as increased production costs are passed through to consumers. The full extent of the inflationary impulse, however, will depend on a number of other things, including the exchange rate regime (fixed or floating), the degree of competition among firms, domestic policy responses and income effects (which will be of opposite sign for an oil importer versus an oil exporter). Another common commodity shock is to food prices, which is likely to have a greater impact on inflation in developing rather than developed economies, since food makes up a higher share of consumption in the developing world.

Finally, similarities in monetary policy reaction functions (Neely and Rapach 2008; Henriksen, Kydland and Sustek 2009) could also be important in explaining the observed co-movement in inflation rates. For example, with authorities becoming more focused on achieving low inflation outcomes around the early 1990s, the move to a low and more stable inflation environment around that time was a common trend in a number of countries. Also, if central banks respond similarly to common shocks or movements in the global business cycle then this could also induce co-movement as domestic inflation responds to the change in policy. Neely and Rapach (2008) find that the common inflation factor in their model is more important for explaining domestic inflation in countries with a greater degree of central bank independence, which could be indicative of similar reaction functions across countries being important.[3]

The explanations for the phenomenon of inflation co-movement outlined above are by no means an exhaustive list, nor are they mutually exclusive. Also, different drivers of global inflation might be more important at different times. We now outline a statistical model that can be used to investigate further the issue of global inflation and some of its potential determinants.

3. A Panel VAR

The panel VAR model outlined below largely follows Canova *et al* (2007) and Canova and Ciccarelli (2009).[4] In this section we outline the key features of the approach. A detailed description of the model and the estimation procedure can be found in Appendix A.

A panel VAR represents an extension of a standard dynamic panel data model to incorporate a vector of variables. In this paper, the G7 economies make up the cross-sectional dimension of the panel, while the 'VAR' part consists of four endogenous variables (output, consumption, investment and the CPI). We also include oil and non-fuel commodities prices (in SDR terms).[5] Initially we treat the commodity variables as exogenously determined but later relax this assumption. The data are quarterly and all variables enter the model in log-differences.

We choose to focus on the G7 economies for two reasons. First, the G7 represents a reasonably homogenous group of economies, in that they are advanced economies with well-developed financial sectors and institutions, and broadly

3 Neely and Rapach (2008) also note, however, that greater central bank independence could plausibly reduce the estimated importance of global inflation.
4 One key difference is that we do not consider time variation in the parameters.
5 A full list of data sources is presented in Appendix C.

similar policy frameworks. As we will see, the panel VAR approach we employ imposes certain similarities on the equations governing the endogenous variables in the model. It is more appropriate then in our application to consider a group of countries that are somewhat similar. Second, this group of countries is well studied and allows our results to be compared to others in the literature. This is not to suggest, however, that other regions, for example, Latin America or east Asia, are unimportant for the study of global inflation, but rather that it is difficult to include a truly global sample of countries using our framework. We also exclude Australia from entering the panel VAR as it is small in a global sense and later we will investigate the significance of co-movement in inflation for modelling inflation in Australia in a separate model.

3.1 The Model

The panel VAR can effectively be thought of as a relatively large VAR, with variables for a number of different countries endogenously determined. For each country, domestic variables are modelled not only as a function of own past lags and other domestic variables, but also as a function of the variables of all other countries. These cross-country lagged interdependencies increase the flexibility and realism of the model and its ability to capture interesting dynamics, such as spillover effects across countries and variables.

It is not feasible, however, to estimate the large number of parameters in a VAR containing 28 endogenous variables (7 countries and 4 variables per country) using the length of data available.[6] Therefore, following Canova *et al* (2007) and Canova and Ciccarelli (2009), we employ a factorisation of the model's coefficients that effectively re-parameterises the panel VAR such that the endogenous variables we want to explain depend on a smaller number of observable factors or 'indicators'. These indicators essentially summarise the key drivers of a larger set of variables,

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6 For each of the NG equations in the panel VAR (N = 7 is the number of countries and G = 4 is the number of endogenous variables per country) there are NGP + CP = 60 coefficients (where P = 2 is the lag length and C = 2 is the number of exogenous variables) for a total number of (NGP + CP)NG = 1 680 coefficients in such an unrestricted VAR.

in a similar fashion to factor models.[7] Equivalently, the approach can be seen as imposing certain restrictions on the parameters of the large VAR. Prior to estimation the data are de-meaned and standardised (as is common practice when working with factor-type models), implying equal weight is given to each country in the panel VAR.

The indicators are, by construction, linear combinations of certain right-hand-side variables of the panel VAR and highlight co-movement between the different series. The factorisation chosen allows us to investigate the importance of common drivers of the endogenous variables in the panel VAR, relative to country-specific, variable-specific or exogenous influences. To illustrate this more clearly, Table 1 shows how the factorisation would work in a simple two-country, two-variable (and one lag) setting. In this example, there are 5 coefficients to estimate, relative to the 16 there would be in an unrestricted VAR with one lag.

Table 1: Panel VAR Example

Two countries (*A* and *B*) and two variables (*X* and *Y*)

Equation	**Right-hand-side indicators**				
	Country-specific		Variable-specific		Common
	$Y^A + X^A$	$Y^B + X^B$	$Y^A + Y^B$	$X^A + X^B$	$Y^A + X^A + Y^B + X^B$
Y^A	β^A	0	α_Y	0	θ
X^A	β^A	0	0	α_X	θ
Y^B	0	β^B	α_Y	0	θ
X^B	0	β^B	0	α_X	θ

Notes: Table entries are coefficients to be estimated in the panel VAR

7 See Canova *et al* (2007) for a discussion of the key differences between the factors generated here and those derived from other factor modelling techniques (for example, those constructed from principal components analysis). This approach to solving the ‘curse of dimensionality’ problem is similar to that used in the global VAR (GVAR) literature, where a linear combination of foreign variables enter as explanatory variables in the VAR (see Pesaran, Schuermann and Weiner (2004)). The GVAR framework has been used to analyse questions related to international trade, global imbalances and international linkages (Dees *et al* 2007; Bussière, Chudik and Sestieri 2009) and could also be a useful framework in which to investigate global inflation.

Extending this approach to our setting, the equation for variable *g* in country *n* is represented by Equation (1).

$$\Delta y_{g,t}^{n} = \mathrm{Z}_{t,\text{common}} + \mathrm{Z}_{t,\text{country}} + \mathrm{Z}_{t,\text{variable}} + \mathrm{Z}_{t,\text{exog}} + \xi_t \tag{1}$$

Equation (1) is representative of all equations in the panel VAR (output growth, consumption growth, investment growth and inflation for each country), with the right-hand-side consisting of:[8]

- *Common indicators* – two common indicators are included, one for the real activity variables and one for inflation, giving equal weight to two lags of each variable for all countries:

$$\mathrm{Z}_{t,\text{common}} = \left(\Sigma_{p=1}^{2}\Sigma_{n=1}^{7}\Sigma_{i=1}^{3}\Delta y_{i,t-p}^{n}\right)\theta_{\text{common}}^{real} + \left(\Sigma_{p=1}^{2}\Sigma_{n-1}^{7}\pi_{t-p}^{n}\right)\theta_{\text{common}}^{inf} \tag{1a}$$

  Where p indexes the two lags, n the seven countries, i the three real variables and $\theta_{\text{common}}^{real}$ and $\theta_{\text{common}}^{inf}$ are the estimated parameters on the real and inflation variables that are common across countries.

- *Country-specific indicators* – two country-specific indicators, one for the real variables and one for inflation, were constructed giving equal weight to two lags of each variable for a single country:

$$\mathrm{Z}_{t,\text{country}} = \left(\Sigma_{p=1}^{2}\Sigma_{i=1}^{3}\Delta y_{i,t-p}^{n}\right)\theta_{n}^{real} + \left(\Sigma_{p=1}^{2}\pi_{t-p}^{n}\right)\theta_{n}^{inf} \tag{1b}$$

  Where the n subscript on θ_{n}^{real} and θ_{n}^{inf} indicates these parameters are estimated just for country n's block of equations in the panel VAR.

8 The residual term in Equation (1) is assumed to be normally distributed, although the specific form of the variance depends on the factorisation imposed (see Appendix A for details). For the baseline results we assume an exact factorisation which implies homoskedastic errors.

- *Variable-specific indicators* – constructed giving equal weight to two lags of either output, consumption or investment growth for all countries:[9]

$$Z_{t,\text{variable}} = \left(\Sigma_{p=1}^{2}\Sigma_{n=1}^{7}\Delta y_{i,t-p}^{n}\right)\theta^{i} \tag{1c}$$

- *Exogenous* indicators – constructed giving equal weight to contemporaneous and one lag of both oil price inflation and non-fuel commodity price inflation:

$$Z_{t,\text{exog}} = \left(\Sigma_{p=0}^{1}\Delta oil_{t-p}\right)\theta_{\text{exog}}^{oil} + \left(\Sigma_{p=0}^{1}\Delta nfuel_{t-p}\right)\theta_{\text{exog}}^{nfuel} \tag{1d}$$

It is important to highlight that when estimating the model we make a distinction between real activity (output, consumption and investment growth) and inflation, with each of the indicators allowed to load with a different coefficient across these two types of equations. The coefficients are, however, restricted to be the same across real variables (except in the case of the variable-specific indicators) and across countries (except in the case of the country-specific indicators). For example, the common real activity indicator is included in each country's output, consumption and investment growth equations and is restricted to have the same coefficient. It is also included in each country's inflation equation but loads with a different coefficient than in the real activity equations. Also, oil prices, for example, are allowed to load differently in real activity and inflation equations.

The key advantage of the factorisation we impose is that there are only 38 coefficients to be estimated, rather than the 1 680 coefficients there would be in an unrestricted panel VAR. Also, the indicators constructed above offer a useful economic interpretation, summarising common, country-specific, variable-specific and exogenous information in the panel VAR.

The model was estimated using Bayesian methods over the sample 1981:Q2 to 2011:Q1 (see Appendix A for details). The next section presents the model

9 A variable-specific indicator for inflation was not included as it is identical to the common inflation indicator in our setup.

estimates and uses the indicators described above to investigate the key drivers of co-movement in inflation in the G7.

4. Results

This section presents the key results from the panel VAR model. First, we document that co-movement in inflation is an important feature of the G7 data, even after controlling for domestic economic activity and common movements in real activity and commodity prices. Second, we investigate which of the key potential drivers of inflation in the model (in particular, the common indicators of real activity and commodity prices) are most important for driving inflation co-movement.

4.1 Co-movement in G7 Inflation

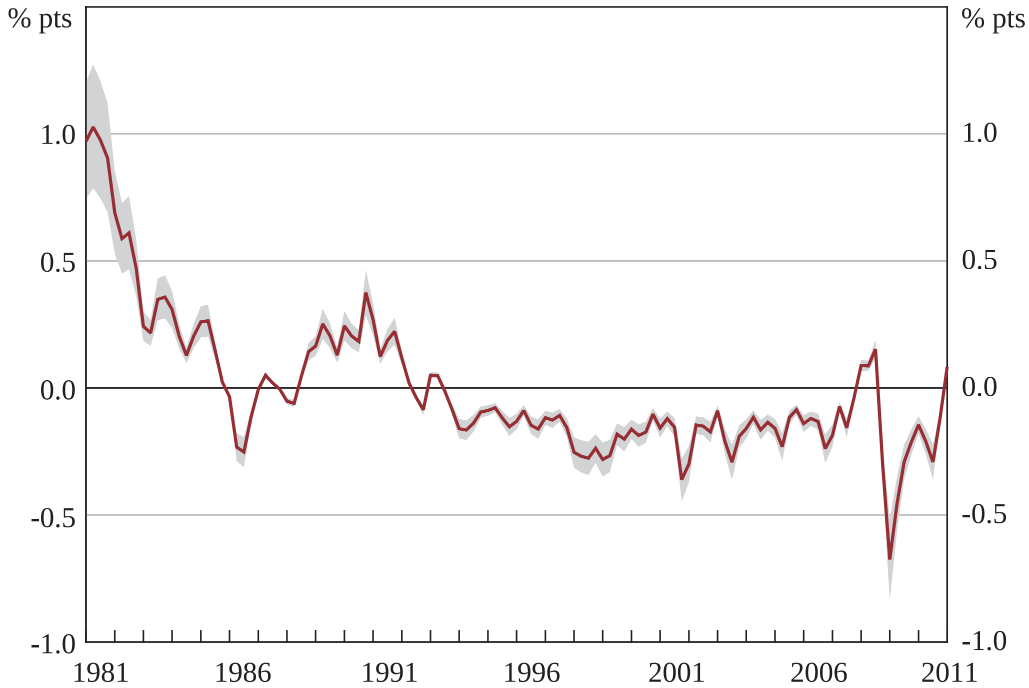
As discussed in the previous section, the common inflation indicator included in the panel VAR was constructed giving equal weight to the two lags of (standardised and de-meaned) quarterly CPI inflation (π_t^n) for all (n = 7) countries. The indicator was included in each country's inflation equation in the panel VAR, and with the same coefficient. The indicator is described in Equation (2):

$$\hat{\mathcal{Z}}_{t,\text{common}}^{inf} = \left(\Sigma_{p=1}^{2}\Sigma_{n=1}^{7}\pi_{t-p}^{n}\right) * p\left(\widehat{\theta_{\text{common}}^{inf}}\right) \tag{2}$$

Where $p\left(\widehat{\theta_{\text{common}}^{inf}}\right)$ represents the estimated posterior distribution of the factor loading. There would be evidence in favour of co-movement in inflation being an important feature of the data if $p\left(\widehat{\theta_{\text{common}}^{inf}}\right)$ is estimated quite precisely and centred away from zero. Or, to put it another way, a significant factor loading would suggest that lags of other country's inflation rates (that is, information on foreign inflation) is a useful explanator of domestic inflation.

Figure 2 plots the median, 5th and 95th percentile of the estimated posterior distribution of the common inflation indicator ($\hat{Z}_{t,\text{common}}^{inf}$).[10] The figure highlights the common nature of inflation experiences, with inflation rates in the individual G7 countries typically either above or below their respective historical averages at the same time. Further, the posterior distribution of the common inflation indicator is estimated quite tightly and is centred away from zero.[11]

Figure 2: Common Inflation Indicator



Notes: Median and 90 per cent posterior interval; calculated from de-meaned and standardised G7 inflation; the indicator has been shifted forward one quarter

This result suggests that movements in foreign inflation have explanatory power for domestic inflation in the G7, even after controlling for other potentially important features of the data. As highlighted earlier, indicators capturing co-movement in real activity and common commodity price movements, along

10 The units of Figure 2 should be interpreted in terms of quarterly de-meaned and standardised inflation. The mean quarterly inflation rate for the G7 countries over the sample is 0.75 per cent, with an average standard deviation of 0.7 per cent.

11 The fact that the posterior uncertainty bands 'shrink' when the indicator is close to zero is a result of the (de-meaned and standardised) inflation data itself being close to zero in certain periods. The posterior uncertainty surrounding the estimated factor loading, however, remains constant throughout.

with country-specific factors (including lagged domestic inflation), were also included in the panel VAR.[12]

Another way to analyse 'global inflation' dynamics in the panel VAR is to consider the effect of 'shocking' different inflation equations. While it is difficult to identify structural shocks in our setting (for example, 'orthogonalised' impulse response functions would require a particular ordering of countries and variables which seems difficult to justify using theory), generalised impulse response functions (GIRFs) (see Koop, Pesaran and Potter (1996) and Pesaran and Shin (1998)) can be constructed that are independent of the ordering of variables and countries. GIRFs consider the effect of a shock (or subset of shocks) to a particular equation (or subset of equations) and integrate out the effect of other shocks according to their historical distribution (we assume the errors follow a multivariate normal distribution). While GIRFs cannot be given a clear structural interpretation, they are informative about the key dynamics of the model and are useful to describe how shocks to different equations evolve through the system.

Figure 3 shows GIRFs of a one standard deviation shock to the US inflation equation in the panel VAR.[13] The median response on domestic inflation in each of the G7 economies over 20 quarters is shown in the left-hand panel, with the median response in the other G7 economies as a whole (average of the G7 excluding the United States) and 90 per cent posterior probability interval shown in the right-hand panel. In the figure, inflation has been re-scaled using the standard deviation of each series (to correspond to actual units) and is presented as an annualised rate.

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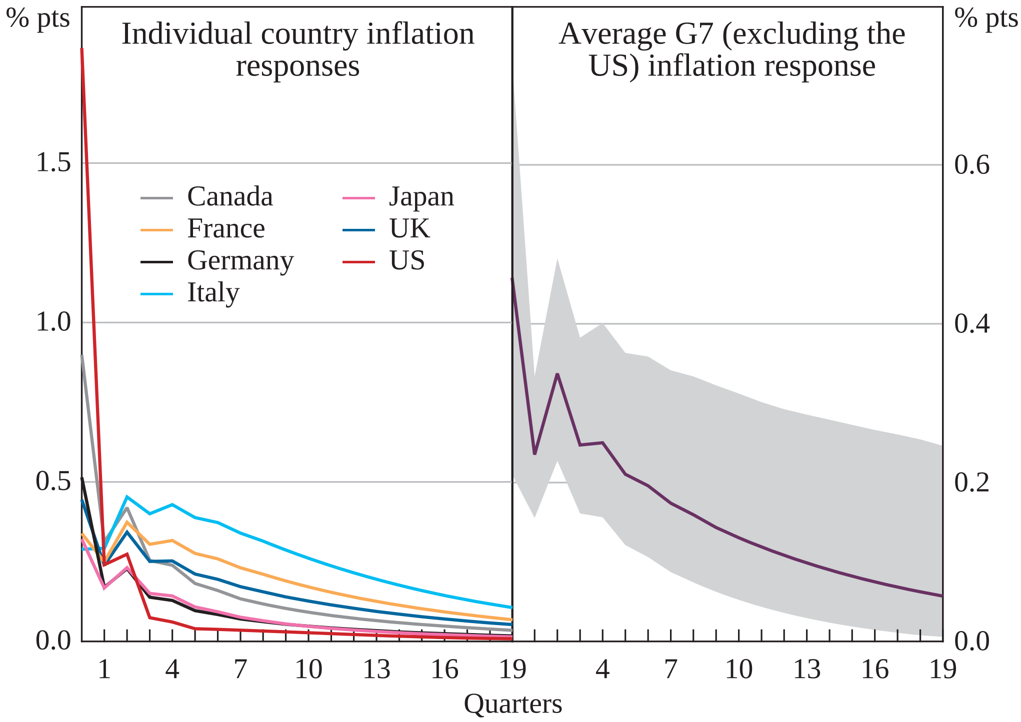
12 The real country-specific indicators were found to be important drivers of real variables for all countries except for Japan, and offered some explanatory power for inflation in the United States, Japan, Germany and the United Kingdom. The country-specific inflation indicators (lags of domestic inflation) were found to be important in all of the inflation equations, and also the real variable equations for the United States, Japan and Canada in particular. We found less evidence of variable-specific effects being important for output, consumption or investment. These results are available on request.

13 The United States was not chosen for any particular reason here and the GIRFs look similar if a different country's inflation equation is shocked instead.

Figure 3: Shock to US Inflation

Median generalised impulse response functions



Notes: One standard deviation shock to the US inflation equation; average G7 (excluding the US) inflation response with 90 per cent posterior interval shown in the right-hand panel

A one standard deviation shock to the US inflation equation in the panel VAR corresponds to an increase in inflation in the United States of around 1¾ percentage points (in annual terms). The shock coincides with a synchronised increase in inflation in the other G7 countries of between 0.3 and 0.9 percentage points on impact. The average response to inflation across countries (excluding the US) is around 0.45 percentage points, with the bulk of the posterior distribution away from zero. The shock is also quite persistent, with inflation at least 0.15 percentage points higher in the other G7 countries, on average, up to two years after the initial shock. These results again highlight the significant cross-country co-movement between inflation rates in the G7. We now turn to discuss the potential drivers of this co-movement.

4.2 What is Driving the Co-movement in G7 Inflation?

4.2.1 Co-movement in real activity

As discussed in Section 3, a common real activity indicator was included in the panel VAR, designed to capture co-movement in real variables across the G7. It was constructed giving equal weight to two lags each of (standardised and de-meaned) output, consumption and investment growth for all countries. The indicator was allowed to load separately in real variable equations, with coefficient $\theta^{1,real}_{\text{common}}$ (Equation (3a)), and inflation equations, with coefficient $\theta^{2,real}_{\text{common}}$ (Equation (3b)).

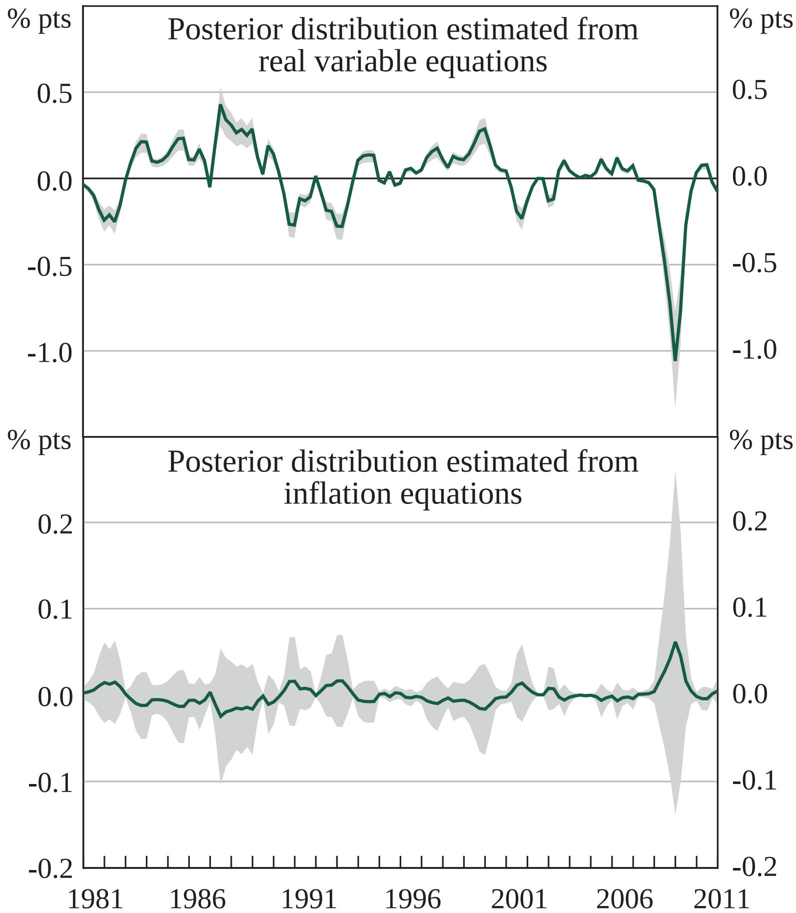
$$\hat{\mathcal{Z}}^{1,real}_{t,\text{common}} = \left(\Sigma^{2}_{p=1}\Sigma^{7}_{n=1}\Sigma^{3}_{i=1}\Delta y^{n}_{i,t-p}\right) * p\left(\widehat{\theta^{1,real}_{\text{common}}}\right) \tag{3a}$$

$$\hat{\mathcal{Z}}^{2,real}_{t,\text{common}} = \left(\Sigma^{2}_{p=1}\Sigma^{7}_{n=1}\Sigma^{3}_{i=1}\Delta y^{n}_{i,t-p}\right) * p\left(\widehat{\theta^{2,real}_{\text{common}}}\right) \tag{3b}$$

To investigate the significance of this indicator for explaining movements in both real activity and inflation across the G7, Figure 4 plots the median, 5th and 95th percentile of the estimated posterior distribution of the common real activity indicators, $\hat{\mathcal{Z}}^{1,real}_{t,\text{common}}$ (top panel) and $\hat{\mathcal{Z}}^{2,real}_{t,\text{common}}$ (bottom panel).

Looking at the top panel of Figure 4, common influences were found to be an important driver of real variables in the data. When the common real activity indicator was included in each of the output, consumption and investment growth equations, the posterior distribution was estimated quite precisely and centred away from zero. This result is consistent with other results in the literature (for example, Kose *et al* (2003) and Canova *et al* (2007)) which find that a common factor can explain a substantial share of variation in real variables across countries.

Figure 4: Common Real Activity Indicator



Notes: Median and 90 per cent posterior interval; calculated from de-meaned and standardised G7 output, consumption and investment growth; the indicators have been shifted forward one quarter

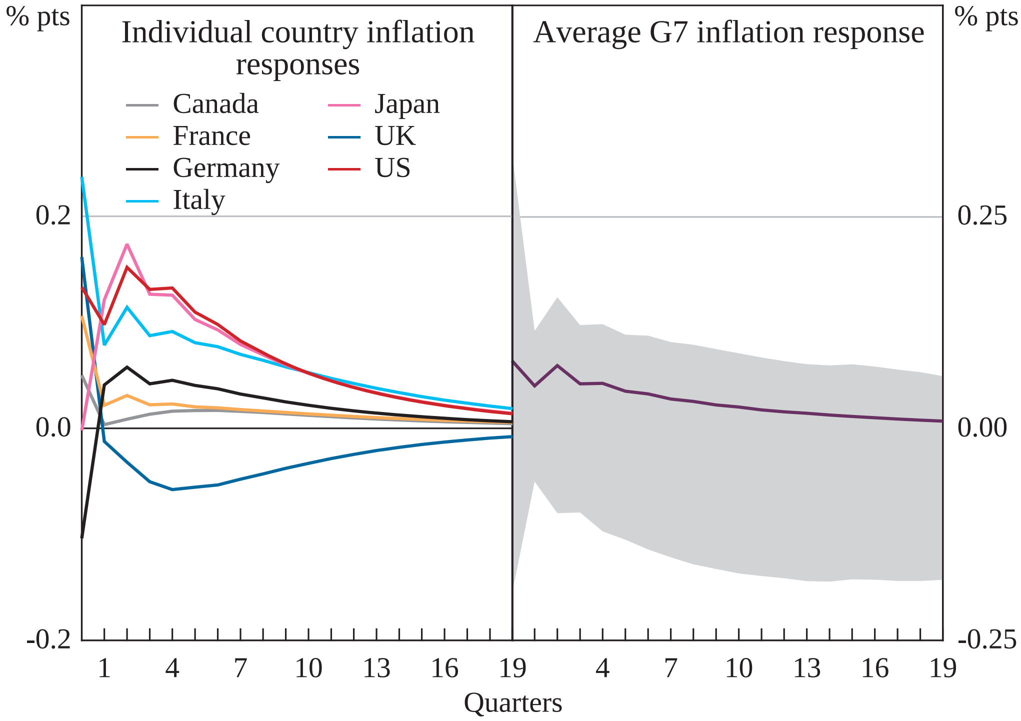
In contrast, co-movement in real activity is not significant in driving fluctuations in inflation across G7 countries. As shown in the bottom panel of Figure 4, the 90 per cent posterior interval of the common real activity indicator includes zero for most of the sample, with the median estimate of the factor loading slightly negative. We can also use GIRFs to investigate the significance of correlated movements in real activity for inflation in the panel VAR. Figure 5 presents GIRFs of inflation to a 'common' shock to real activity, defined as a one standard deviation shock to a subset of equations – output, consumption and investment – for all countries in the panel VAR.[14] On impact, the positive shock increases output, consumption and investment by, on average across countries, around 0.35,

14 See Koop *et al* (1996) and Dees *et al* (2007) for a discussion of how a subset of system-wide shocks can be analysed in the generalised impulse response framework.

0.25 and 0.75 per cent, respectively. The median individual country inflation responses to this shock are shown in the left-hand panel of Figure 5, with the median response for inflation in the G7 as a whole (calculated as the average across countries) and 90 per cent posterior probability interval shown in the right-hand panel.

Figure 5: 'Common' Shock to Real Activity

Median generalised impulse response functions



Notes: One standard deviation shock to output, investment and consumption growth for all countries; average G7 inflation response with 90 per cent posterior interval shown in the right-hand panel

The results suggest that the 'common' positive shock to real activity, as characterised here, does increase inflation in some countries but by a modest amount, with the response across countries less synchronised than was the case following the shock to US inflation (Figure 3). The 90 per cent posterior band for the average G7 inflation response is also relatively wide and includes zero (this is also the case for the individual country responses).

Correlated movements in real activity, therefore, do not seem to be a significant driver of G7 inflation in the panel VAR. A possible reason for this finding is that a reasonable part of our estimation sample from 1981:Q2 to 2011:Q1 is comprised of the 'great moderation', a period that has seen a reduction in the variability of both real activity and inflation. Given this, it may be harder to precisely estimate the relationship between these variables. It has also been argued that this period has seen a substantial ‘flattening’ of the Phillips curve (see, among others, Beaudry and Doyle (2000) and Roberts (2006)), with inflation less responsive to changes in output. It is also worth emphasising again that generalised impulse responses cannot be given a clear structural interpretation. Given that the ‘common shock to real activity’ characterised above could reflect both demand and supply shocks (which would have opposite effects on inflation) this may also be a reason for the muted estimated inflation response.

Another important point is that the correlations we are interested in are likely to be unstable over time. One limitation of our analysis is that we do not allow for time variation in the parameters of the model. It could be the case that common movements in real activity are more important at particular times. For example, the synchronised fall in economic activity experienced following the global financial crisis (see Figure 4, top panel) was associated with a synchronised fall in inflation across countries (see Figure 2). During this particular period, synchronised movements in real activity could have been an important driver of this inflation co-movement. Non-linear effects are also not considered here (see Stock and Watson (2010) for further discussion on the stability of inflation forecasting models, particularly during downturns).

Nevertheless, overall these results would suggest that we need to look elsewhere to explain the observed co-movement in inflation rates seen in the data.

4.2.2 Common shocks to commodity prices

As discussed in Section 3, oil and non-fuel commodity prices were included as exogenous variables in the panel VAR as a way to control for particular common shocks to which all countries are exposed. The simple average of contemporaneous and lagged oil price inflation was found to be a significant explanator of inflation in the panel VAR. The median coefficient estimate was positive, with the 90 per cent posterior probability interval away from zero. The median coefficient estimate in the panel VAR implies that a 10 per cent shock to oil prices increases headline inflation in the G7 by, on average across countries, around 0.2 percentage points in annual terms in the same period. The non-fuel commodity price variable was also found to be important for explaining inflation (the contemporaneous inflation response to a 10 per cent increase in non-fuel commodity prices in the panel VAR was, on average across countries, around 0.2 percentage points). For the real activity variables in the panel VAR, non-fuel commodity prices, but not oil prices, were found to be a significant explanator.

Commodity prices therefore seem to be an important driver of headline inflation across countries, which could go some way to explaining the observed co-movement in inflation rates observed in the data. The assumption that commodity prices are exogenous to the other variables in the panel VAR, however, is perhaps too restrictive and could lead to biased estimates of the contemporaneous impact of commodity prices on inflation. For example, common movements in real activity (reflected in the common real activity indicator in the panel VAR) could influence global commodity demand and therefore commodity prices. Therefore, to check this result, an alternative specification was also estimated in which commodity prices are endogenously determined in the panel VAR. In particular, the oil and non-fuel commodity price inflation variables were assumed to be explained by lags of each other, but also by the common real activity and common inflation indicators included in the panel VAR. Figure 6 presents GIRFs of a 10 per cent shock to oil prices on inflation in the G7 under this alternative specification.[15]

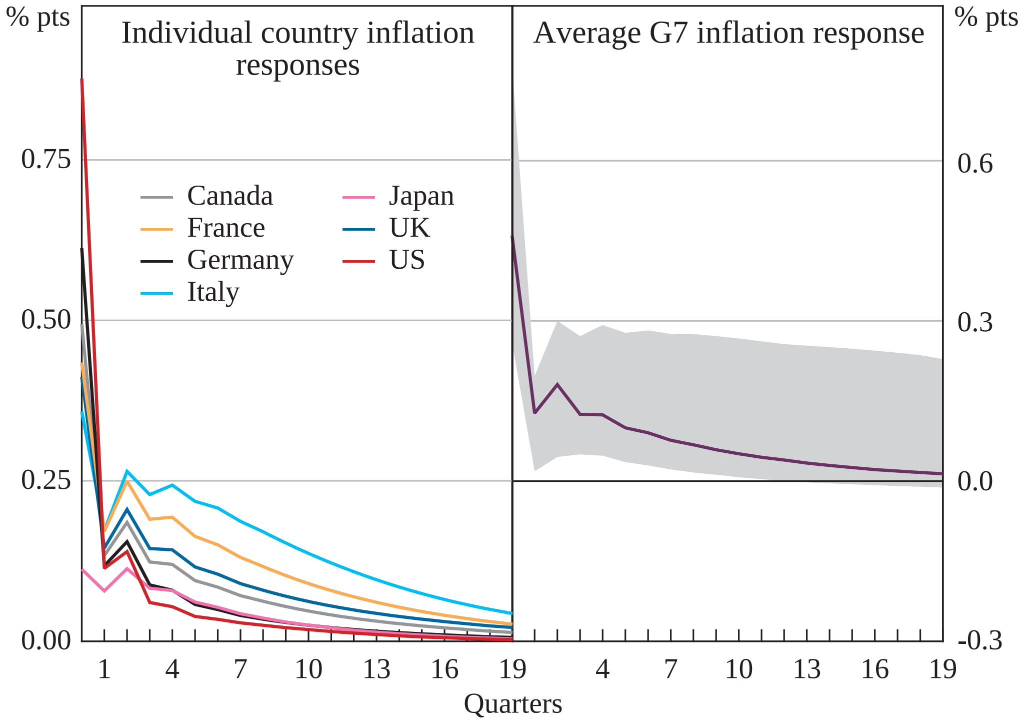
The GIRFs reported in Figure 6 again support the idea that common shocks to commodity prices are a key candidate for explaining the observed co-movement in headline inflation in the G7. The shock to the oil price equation in the panel VAR leads to a synchronised increase in inflation across the G7, with inflation initially increasing by between 0.1 and 0.9 percentage points across countries and by 0.45 percentage points on average (with the 90 per cent posterior probability interval away from zero for up to two years after the shock). Under this alternate specification, with commodity prices allowed to be endogenous, a shock to non-fuel commodity prices was also found to have a significant impact on inflation

15 It is also worth noting that in the specification with commodity prices endogenously determined, we do not restrict the contemporaneous impact of oil prices to be the same across countries (as is the case when commodity prices are assumed exogenous and enter the model contemporaneously and with the same coefficient across countries).

(although part of this is due to the fact that movements in non-fuel commodity prices have historically been associated with an increase in oil prices and GIRFs are not 'orthogonalised').

Figure 6: Shock to Oil Prices

Median generalised impulse response functions

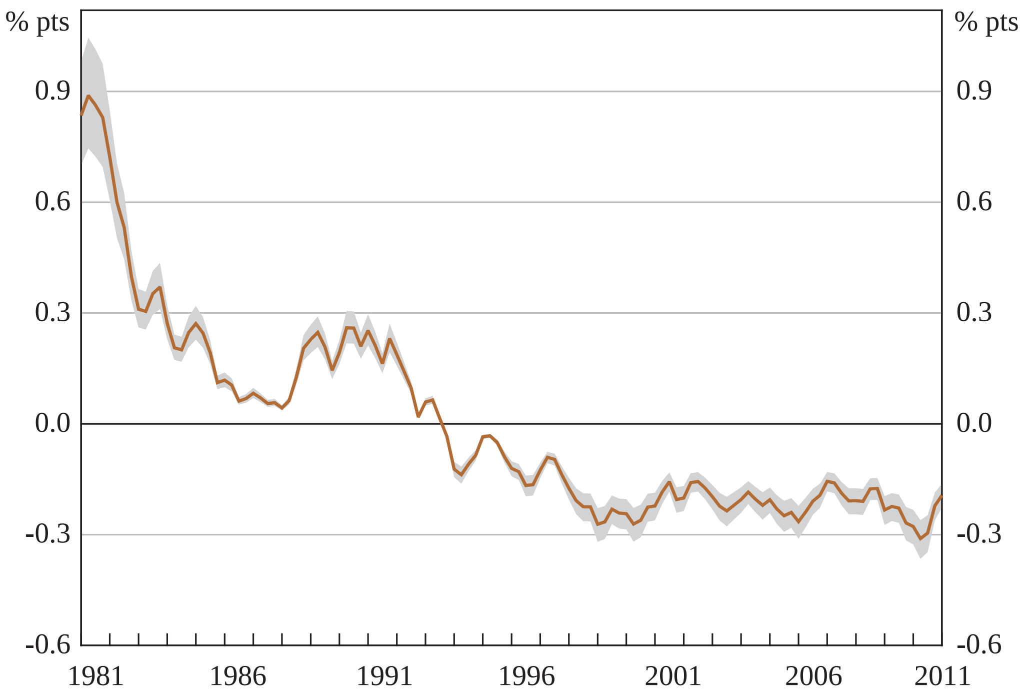


Notes: Ten per cent shock to oil prices; average G7 inflation response with 90 per cent posterior interval shown in the right-hand panel

Another way to consider the role of commodity prices in driving global inflation dynamics is to model consumer prices excluding food and energy; that is, core, rather than headline, inflation. By removing food and energy price movements from the headline measure we strip out the direct first-round impact of shocks to food and energy prices on consumer prices. If movements in these variables are indeed an important driver of the significant correlation between headline G7 inflation rates, we would expect to see less evidence of core inflation moving together across countries. Figure 7 presents the common inflation indicator from the panel VAR model estimated using core, rather than headline, inflation, while Figure 8 shows GIRFs of a one standard deviation shock to the US core inflation equation.

As can be seen in Figure 7, the estimated loading on the common core inflation indicator was still found to be positive and estimated quite precisely, suggesting that there is also evidence of co-movement in core inflation rates being an important feature of the data. In contrast to the panel VAR estimated using headline inflation, however, the contemporaneous impact of a shock to US core inflation on the rest of the G7 (Figure 8) is close to zero and insignificant (the peak response is lagged by around a year and although the 90 per cent posterior probability interval is slightly away from zero further out, the magnitude of the average response remains relatively small). So while there is still evidence of co-movement in core inflation rates in the G7, it is perhaps somewhat less pronounced than in the headline data. This seems consistent with the notion of common shocks to commodity prices being an important determinant of inflation co-movement.

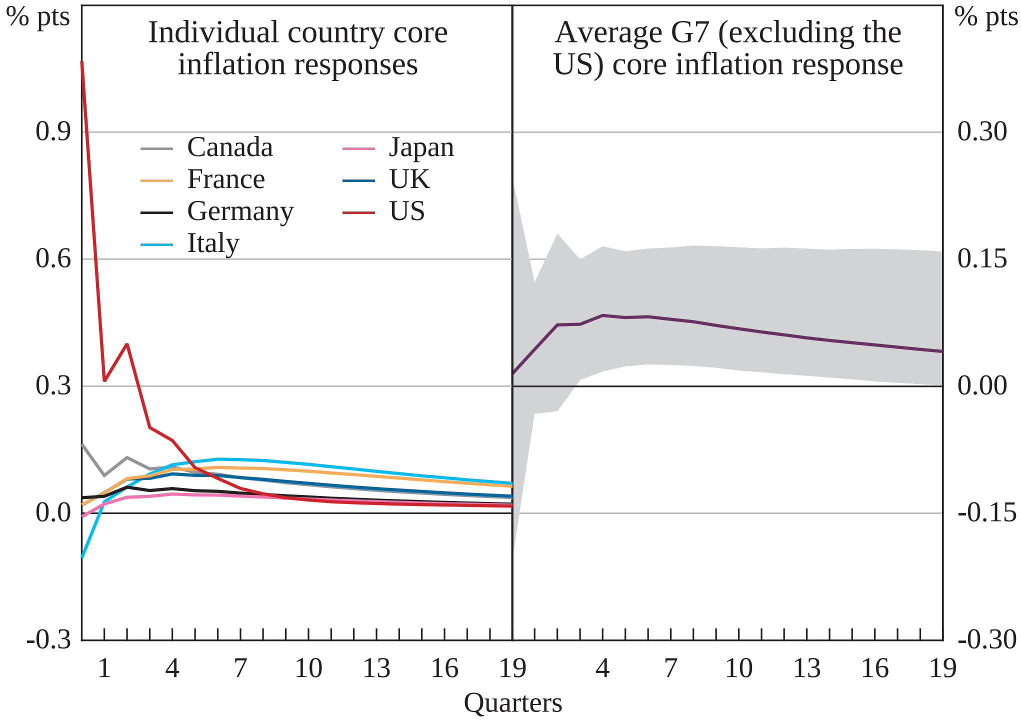
Figure 7: Common Core Inflation Indicator



Notes: Median and 90 per cent posterior interval; calculated from de-meaned and standardised G7 core (CPI excluding food and energy) inflation; the indicator has been shifted forward one quarter

Figure 8: Shock to US Core Inflation

Median generalised impulse response functions



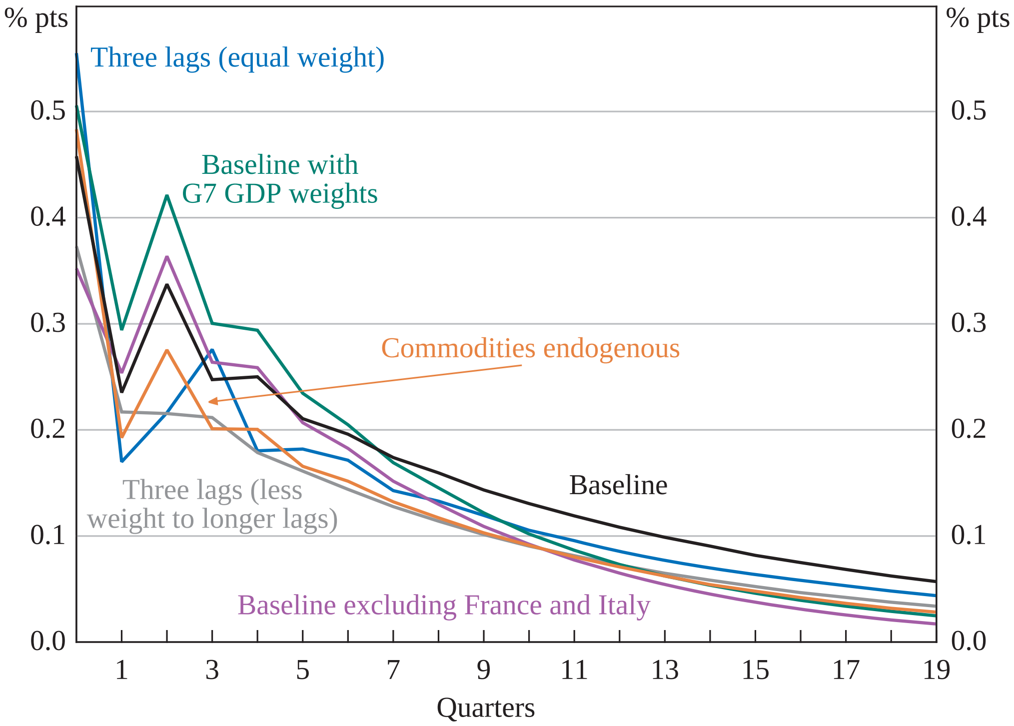
Notes: One standard deviation shock to the US core inflation equation; average G7 (excluding the US) inflation response with 90 per cent posterior interval shown in the right-hand panel

4.3 Robustness

A number of different specifications of the panel VAR model outlined above were estimated to check the robustness of the results. In particular, versions of the model were tried using different lag lengths and also giving declining weight to longer lags when constructing the various indicators. Country weights corresponding to GDP at market exchange rates (on average over the sample) were also tried as opposed to giving equal weight to each country. A version of the model excluding France and Italy was also estimated to see whether including multiple European countries (with the same exchange rate for part of the sample) was influencing the results. And as mentioned above, a version of the model where commodity prices are endogenously determined was also estimated. The results were generally found to be robust to these alternate specifications. For example, Figure 9 plots the average G7 (excluding the United States) inflation GIRF to a US inflation shock (the same shock shown in Figure 3) under different specifications of the panel VAR.

Figure 9: Robustness – Shock to US Inflation

Average G7 (excluding the US) inflation response

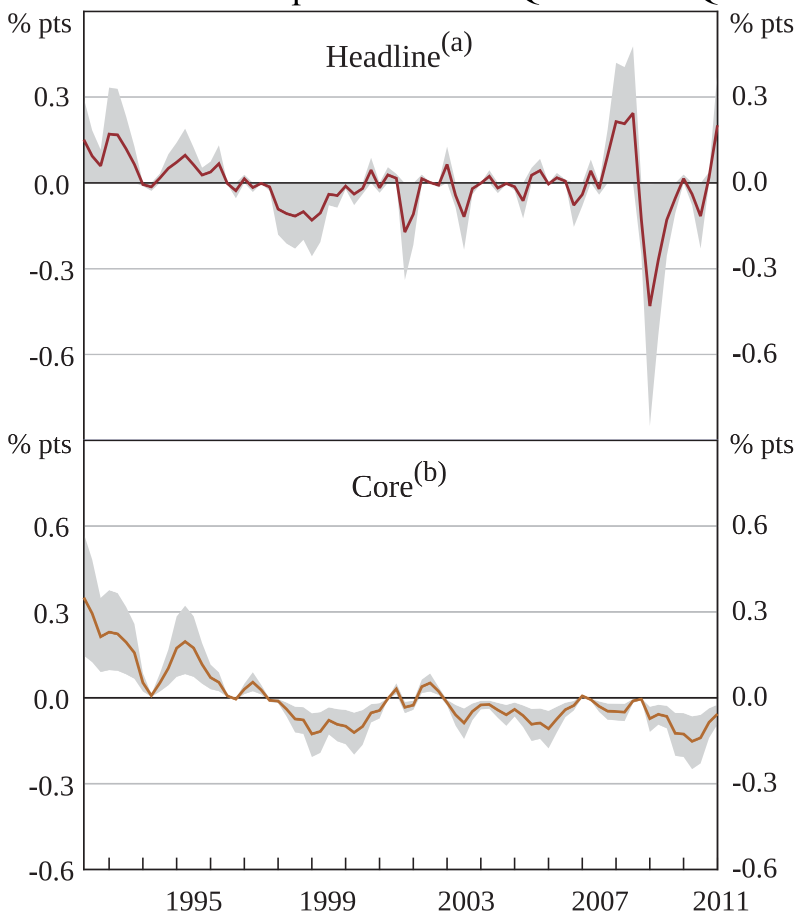


Notes: Median generalised impulse response functions; one standard deviation shock to the US inflation equation

The baseline panel VAR was also estimated over a more recent 'low-inflation' sample from 1992:Q1 to 2011:Q1, using a prior initialised over the earlier sample period. This is important to consider since the policy shift towards inflation targeting around the early 1990s is potentially a key regime change in our sample. The transition from a period of relatively high and volatile inflation to lower and more stable inflation in the early 1990s was common to each of the G7 economies. From a purely statistical point of view, the co-movement in inflation rates around this time could be a key driver of the global inflation result. The posterior distribution of the common inflation indicator (both the headline and core version) estimated over this 'low-inflation' sample is shown in Figure 10. While estimated somewhat less precisely relative to the full sample, the indicators were still found to be an important explanator of domestic inflation in the panel VAR. This would suggest that the shift to low inflation cannot account for all of the co-movement in inflation rates observed in the data.

Figure 10: Common Inflation Indicator

Estimation sample from 1992:Q1 to 2011:Q1



Notes: Median and 90 per cent posterior interval

(a) Calculated from de-meaned and standardised G7 inflation

(b) Calculated from de-meaned and standardised G7 core (CPI excluding food and energy) inflation

Finally, a version of the panel VAR was also estimated in which the factorisation of the coefficients (essentially restrictions) described earlier was not assumed to be exact (see Appendix A). The results obtained were again similar to those reported above. We also estimated the model using feasible least squares and calculated robust standard errors as an additional robustness check. Again the results were similar (see Appendix B).

5. Implications for Modelling Inflation in Australia

The significant correlation between inflation rates across countries is something that could be exploited for understanding the dynamics of domestic inflation in Australia. Furthermore, the results presented so far in this paper suggest that movements in global inflation may reflect, in part, information other than what can be gleaned from data on foreign real activity and movements in commodity prices. The significance of global inflation for explaining domestic inflation, however, will depend on a number of factors. For example, while movements in commodity prices are a potential key driver of co-movement in inflation rates across countries, in Australia (a commodity exporter) the floating exchange rate could work to offset somewhat the impact of higher commodity prices on inflation, since a positive shock to commodity prices is likely to be associated with an appreciation of the Australian dollar. Pass-through to domestic prices may be delayed, however, for a number of reasons (such as, foreign exchange hedging, pricing to market), in which case exchange rate fluctuations need not perfectly offset a change in foreign prices. It remains an empirical question, therefore, as to whether or not we may still see significant co-movement in inflation rates in the near term.

To test the significance of foreign inflation in explaining domestic inflation in Australia, models for both headline and underlying (trimmed mean) inflation following Norman and Richards (2010) were estimated. The Phillips curve and mark-up model specifications were augmented with the average of quarterly G7 headline inflation, similar to the measure of global inflation used in the panel VAR (which averages G7 inflation over two periods), as an additional explanatory variable.[16] The same oil and non-fuel commodity price variables used in the panel VAR were also included. As Australia can be considered a small open economy, G7 inflation enters the regressions contemporaneously (and with one lag), as do both commodity price variables.

The results are reported in Tables 2 and 3, over the estimation sample from 1990:Q1 to 2011:Q1. A positive and statistically significant coefficient on the G7 inflation variable would be evidence in favour of foreign inflation being an important explanator of inflation in Australia.

16 The results are qualitatively similar if the common inflation indicator from the panel VAR is used instead. The simple average is also very close to the first principle component of G7 inflation rates (as principle component analysis assigns close to equal weight to each of the series). Using an OECD-wide measure was also found to give similar results.

Table 2: Standard Phillips Curve Model

Estimation sample 1990:Q1 to 2011:Q1

Dependent variable	Headline inflation		Trimmed mean inflation	
	(1)	(2)	(3)	(4)
Lagged inflation	–0.377**	–0.409*	0.233	0.233
Inflation expectations	0.598***	0.395**	0.311***	0.188**
Unemployment rate	0.107**	0.123***	0.102***	0.108***
Change in unemployment rate	–0.003	–0.003*	–0.002***	–0.002***
Import price inflation	0.119	0.104	0.035	0.032
Oil price inflation	0.014***	0.007**	0.004*	0.002
Non-fuel commodity price inflation	0.018**	0.013	–0.007*	–0.010*
G7 inflation (*t*)		**0.562*****		**0.192****
G7 inflation (*t–1*)		**–0.115**		**0.052**
Adjusted R^2	0.354	0.401	0.712	0.723

Notes: Models (2) and (4) include G7 inflation; sum of coefficients and *p*-values from Wald tests for joint significance are reported; ***, ** and * indicate significance at the 1, 5 and 10 per cent level, respectively; two lags were included for domestic inflation; import price inflation enters as a polynomial distributed lag; oil and non-fuel commodity price inflation and G7 inflation enter contemporaneously and with one lag. Both the headline and trimmed mean inflation measures exclude interest, tax and health policy changes and exclude the deposits and loans component of the CPI; see Norman and Richards (2010) for more details.

The regression results suggest that foreign inflation does have explanatory power for domestic inflation in Australia (in line with the results for the G7 presented earlier), particularly headline inflation. The coefficient on contemporaneous G7 inflation is highly significant in the headline inflation regressions and including G7 inflation improves the in-sample fit of both models considerably (as measured by the adjusted R-squared). Over the 1990:Q1–2011:Q1 sample, the contemporaneous impact of a 1 percentage point increase in G7 headline inflation is to increase domestic headline inflation by around 0.5 percentage points. While also statistically significant (at around the 5 per cent level), foreign inflation seems to offer little additional explanatory power in the trimmed mean inflation regressions. The impact of a 1 percentage point increase in G7 inflation on underlying inflation is also smaller, with trimmed mean inflation increasing by around 0.2 percentage points in the same quarter. The results also find some evidence of commodity prices affecting headline inflation, in particular, in the same quarter.[17] However, the coefficients on oil and non-fuel commodity price inflation are smaller (and become less significant or insignificant) when the G7 inflation variable is included. The role of inflation expectations for explaining domestic inflation also falls somewhat when G7 inflation is included as an additional explanator.

Table 3: Mark-up Model

Estimation sample 1990:Q1 to 2011:Q1

Dependent variable	**CPI inflation**		**Trimmed mean inflation**	
	(1)	(2)	(3)	(4)
Lagged inflation	–0.335*	–0.347*	0.378**	0.410***
Inflation expectations	0.464**	0.280	0.153*	0.049
Output gap	0.112	0.130	0.099*	0.116*
Growth in real unit labour costs	0.182	0.196	0.123**	0.104**
Import price inflation	0.175	0.166	0.079	0.077
Oil price inflation	0.015***	0.009**	0.005*	0.003
Non-fuel commodity price inflation	0.016**	0.011	–0.005*	–0.008
G7 inflation (*t*)		**0.534****		**0.174***
G7 inflation (*t*–*1*)		**–0.155**		**0.038**
Adjusted R^2	0.333	0.374	0.697	0.706

Notes: Models (2) and (4) include G7 inflation; sum of coefficients and *p*-values from Wald tests for joint significance are reported; ***, ** and * indicate significance at the 1, 5 and 10 per cent level, respectively; two lags were included for domestic inflation; growth in real unit labour costs and import price inflation enter as a polynomial distributed lag; oil and non-fuel commodity price inflation and G7 inflation enter contemporaneously and with one lag. Both the headline and trimmed mean inflation measures exclude interest, tax and health policy changes and exclude the deposits and loans component of the CPI; see Norman and Richards (2010) for more details.

In line with the earlier results, foreign inflation seems to offer more information for explaining headline inflation than underlying inflation. Given headline inflation is more sensitive to fuel and food prices than is trimmed mean inflation, this suggests a key role for commodity prices in driving inflation co-movement. It remains somewhat of a puzzle, however, as to why G7 inflation is still found to be

17 These results were found to be robust to the inclusion of the common real activity indicator (contemporaneously and with lags) from the panel VAR as a proxy for international economic activity.

significant in the above regressions. Notably, controlling for commodity prices and import prices (and global activity – although this variable was found to be insignificant and is not included in the above results) should account for explanations emanating from business cycle correlations and pass-through of shocks to traded goods prices. An alternative explanation may relate to the difficulties in measuring variables such as import prices, and in particular the dynamics of their impact on inflation, and so foreign inflation may help to proxy for these impacts.

In the Australian data, it also seems that the bulk of the explanatory power of G7 inflation is coming through the contemporaneous term (when only the first lag of G7 inflation is included its coefficient was also found to be insignificant in each of the regressions). This result seems consistent with the idea that the endogenous response of the exchange rate could be working to offset (with some lag) the effect of an impulse to global inflation. Well-anchored inflation expectations are also likely to have helped limit second-round type effects.

Finally, the result that movements in international inflation have explanatory power for domestic inflation is also an interesting finding from a forecasting perspective. Stock and Watson (2007) discuss the fact that in recent times inflation has become harder to forecast, in the sense that it is difficult to find useful predictors of inflation. Cicarelli and Mojon (2010) consider a forecasting exercise (which includes data for Australia) and find that including information on global inflation can improve forecasting accuracy relative to simple univariate benchmark models. As a simple 'nowcasting' exercise, we also included in the above regressions a measure of G7 inflation constructed using less than the full quarter's worth of inflation data. Measures using only the first two months, and first month, of inflation data for the relevant quarter were also generally found to be significant in the above regressions (although the estimated coefficients were somewhat lower), suggesting the monthly frequency of inflation data in the G7 could be used to inform predictions of (quarterly) Australian inflation. However, history would suggest it would be wise to be cautious about the stability of various relationships for predicting inflation. The emergence of Asia, for example, presents a key structural change taking place in the global economy, with potentially important implications for global inflation dynamics.[18]

6. Conclusion

This paper has presented a panel VAR model for the G7 economies that allows for rich interactions between countries and variables while maintaining a parsimonious model structure. Following Canova *et al* (2007) and Canova and Ciccarelli (2009), observable factors or indicators were obtained from the model, highlighting co-movement between the series in the panel VAR. The model was used as a framework to investigate the issue of global inflation.

While not presenting a structural explanation, the panel VAR was used to evaluate different possible interpretations of the correlation in inflation rates across countries observed in the data. Common shocks to commodity prices, but not to global real activity, were found to be important for driving 'global inflation' dynamics. However, there is still statistical evidence of co-movement in G7 inflation rates even after controlling for the possible influence of commodity prices and global activity.

Given the role of the common inflation indicator in explaining inflation in the G7 countries, it was then also investigated whether global inflation has a significant influence on Australian inflation. To do this, a global inflation measure was added to standard single equation models for headline and underlying inflation in Australia. The results again indicate that movements in international inflation contain useful information for explaining domestic inflation, particularly headline inflation.

18 Neely and Rapach (2008) found that country characteristics such as the degree of openness, institutional quality, financial development and real GDP per capita were all associated with an increasing role for global inflation in explaining domestic inflation.

Appendix A: The Panel VAR

A.1 The Model in More Detail[19]

Consider a dynamic panel data model shown in Equation (A1) where $y_{i,t}$ represents an observation for cross-section $i = 1,\ldots,N$ in time period $t = 1,\ldots,T$

$$y_{i,t} = \beta^i_1 y_{i,t-1} + \beta^i_2 y_{i,t-2} + \cdots + \beta^i_p y_{i,t-p} + e_{i,t} \tag{A1}$$

If we generalise Equation (A1) and allow $y_{i,t}$ to be a vector of G variables, denoted in bold as $\mathbf{y}_{i,t}$, then Equation (A2) below represents a panel VAR model:

$$\mathbf{y}_{i,t} = \mathbf{D}^i_1 \mathbf{Y}_{t-1} + \mathbf{D}^i_2 \mathbf{Y}_{t-1} + \cdots + \mathbf{D}^i_p \mathbf{Y}_{t-p} + \mathbf{e}_{i,t} \tag{A2}$$

Where $\mathbf{Y}_t$ represents the NG × 1 vector formed by stacking the vector $\mathbf{y}_{i,t}$ in the cross-sectional dimension, that is, $\mathbf{Y}_t = \left[\mathbf{y}'_{1,t}, \mathbf{y}'_{2,t}, \ldots, \mathbf{y}'_{\mathrm{N},t}\right]'$, and $\mathbf{D}^i_1,\ldots,\mathbf{D}^i_{\mathbf{p}}$ are G × NG matrices of coefficients for up to P lags of $\mathbf{Y}_t$ to be included in the VAR. Note also that $\mathbf{e}_{i,t}$ is a G × 1 vector of mean zero and iid errors. Finally, denoting $\mathbf{D_1},\ldots,\mathbf{D_p}$ as stacked-by-i NG × NG matrices of coefficients, and also allowing for a C × 1 vector of exogenous explanatory variables denoted $\mathbf{C}_t$ with coefficient matrix $\mathbf{A}$, then we obtain Equation (A3):

$$\mathbf{Y}_t = \mathbf{D_1}\mathbf{Y}_{t-1} + \mathbf{D_2}\mathbf{Y}_{t-2} + \cdots + \mathbf{D_P}\mathbf{Y}_{t-P} + \mathbf{A_0}\mathbf{C}_t + \cdots + \mathbf{A_{P-1}}\mathbf{C}_{t-P+1} + \mathbf{E}_t \tag{A3}$$

Where $\mathbf{E}_t$ is a NG × 1 vector of random disturbances, $\mathbf{E}_t \sim \mathrm{N}(\mathbf{0},\mathbf{\Omega})$.

Define $\mathbf{X}_t = \left[\mathbf{Y}'_{t-1}, \mathbf{Y}'_{t-2}, \ldots, \mathbf{Y}'_{t-P}, \mathbf{C}'_t, \ldots, \mathbf{C}'_{t-P+1}\right]'$ as the vector formed by stacking the P lags of the right-hand-side variables. Now we can write Equation (A3) as a system of the form:

$$\mathbf{Y}_t = \mathbf{W}_t \boldsymbol{\delta} + \mathbf{E}_t \tag{A4}$$

19 The notation in this section largely follows Canova *et al* (2007).

$$\boldsymbol{\delta} = \boldsymbol{\Xi}_1\theta_1 + \boldsymbol{\Xi}_2\theta_2 + \cdots + \boldsymbol{\Xi}_{\mathrm{K}}\theta_{\mathrm{K}} + \mathbf{u} \tag{A5}$$

Where in the above equations $\mathbf{W}_t = \mathbf{I}_{\mathrm{NG}} \otimes \mathbf{X}_t'$, $\boldsymbol{\delta}_i$ is a (NGP + CP) × 1 vector formed by stacking the rows of $\mathbf{D} = \left[\mathbf{D_1},\ldots,\mathbf{D_p},\mathbf{A_0},\ldots,\mathbf{A_{P\text{-}1}}\right]$ and finally $\boldsymbol{\delta}$ is formed by stacking $\boldsymbol{\delta}_i$ and is a vector containing all the coefficients of the system.

Equation (A5) describes the factorisation of the coefficients vector as discussed in the main text. We include common, country-specific and variable-specific factors, alongside the exogenous variables as key drivers of the data. In Equation (A5), the dimension of $\left[\theta_1,\theta_2,\ldots,\theta_k\right]' = \left[\boldsymbol{\theta}_{\text{common}},\boldsymbol{\theta}_{\text{country}},\boldsymbol{\theta}_{\text{variable}},\boldsymbol{\theta}_{\text{exog}}\right]' = \boldsymbol{\theta}$ is 38 × 1, much smaller than the total number of coefficients in the unrestricted model and making estimation feasible using a realistic sample size. The $\boldsymbol{\Xi}_k$'s represent matrices of appropriate dimensions made up of 1's and 0's and are designed to pick out the relevant coefficients relating to our factorisation. The error term $\mathbf{u} \sim \mathrm{N}\left(\mathbf{0},\boldsymbol{\Omega}\otimes\mathbf{V}\right)$ captures un-modelled features of $\boldsymbol{\delta}$ and throughout we assume that $\mathbf{V} = \sigma^2\mathbf{I}_{\mathrm{NGP+CP}}$.[20]

Finally, substituting Equation (A5) into Equation (A4), we get:

$$\mathbf{Y_t} = Z_{t,\text{common}} + Z_{t,\text{country}} + Z_{t,\text{variable}} + Z_{t,\text{exog}} + \boldsymbol{\xi}_t \tag{A6}$$

Where
$Z_{t,\text{common}} = \mathbf{W}_t\boldsymbol{\Xi}_{\text{common}}\boldsymbol{\theta}_{\text{common}}, Z_{t,\text{country}} = \mathbf{W}_t\boldsymbol{\Xi}_{\text{country}}\boldsymbol{\theta}_{\text{country}}, Z_{t,\text{variable}} = \mathbf{W}_t\boldsymbol{\Xi}_{\text{variable}}\boldsymbol{\theta}_{\text{variable}}$ and $Z_{t,\text{exog}} = \mathbf{W}_t\boldsymbol{\Xi}_{\text{exog}}\boldsymbol{\theta}_{\text{exog}}$ and the error term $\boldsymbol{\xi}_t = \mathbf{W}_t\mathbf{u} + \mathbf{E}_t \sim \mathrm{N}\left(\mathbf{0},\sigma_t\boldsymbol{\Omega}\right)$ where $\sigma_t = 1 + \sigma^2\mathbf{X}_t'\mathbf{X}_t$.[21]

20 Canova and Ciccarelli (2009) provide a detailed example of this setup in a simple two-country and two-variable setting.

21 For $\sigma^2 > 0$ the model implies a specific form of heteroskedasticity in the error term.

A.2 Estimating the Model

Bayesian methods were used to estimate the panel VAR. Equation (A7) represents the seemingly unrelated regression (SUR) form of the model:

$$\mathbf{Y}_t = \mathbf{W}_t\left(\boldsymbol{\Xi\theta} + \mathbf{u}\right) + \mathbf{E}_t = \boldsymbol{\chi}_t\boldsymbol{\theta} + \boldsymbol{\xi}_t \tag{A7}$$

Where $\boldsymbol{\Xi} = \left[\boldsymbol{\Xi}_1, \boldsymbol{\Xi}_2, \ldots, \boldsymbol{\Xi}_k\right]$ and $\boldsymbol{\theta} = \left[\theta_1, \theta_2, \ldots, \theta_k\right]'$. It should be clear that for $\sigma^2 > 0$ the error term implied by the model is heteroskedastic, where $\sigma_t = 1 + \sigma^2\mathbf{X}_t'\mathbf{X}_t$.[22] While in the baseline estimation we set $\sigma^2 = 0$, it is also possible to treat σ^2 as a parameter to be estimated.

We employ a semi-conjugate prior for the parameters $\boldsymbol{\theta}$, σ^2 and $\boldsymbol{\Omega}$:

$$p\left(\boldsymbol{\theta}, \sigma^2, \boldsymbol{\Omega}\right) = p\left(\boldsymbol{\theta}\right) p\left(\sigma^2\right) p\left(\boldsymbol{\Omega}\right) \tag{A8}$$

Where $p\left(\boldsymbol{\theta}\right) \sim \mathrm{N}\left(\boldsymbol{\theta}_0, \mathbf{V}_0\right), p\left(\sigma^2\right) \sim \mathrm{IG}\left(\frac{a_0}{2}, \frac{a_0 s^2}{2}\right)$ and $p\left(\boldsymbol{\Omega}\right) \sim \mathrm{IW}\left(z_0, \mathbf{Q}_0^{-1}\right)$.

When estimating the model over the full sample of data from 1981:Q2 to 2011:Q1 an uninformative prior was used. When estimating the model over the 'low-inflation' sample a training sample from 1981:Q2 to 1991:Q2 was used to initialise the prior. Specifically, the prior mean for the coefficients vector was set equal to the OLS estimate of the SUR model using the training sample, with a prior variance equal to the identity matrix. For the inverse Wishart prior for $\boldsymbol{\Omega}$ we set $z_0 = \mathrm{NG} + T_0$ (where $T_0 = 41$ is the size of the training sample) and $\mathbf{Q}_o = \hat{\mathbf{Q}}_0$ where $\hat{\mathbf{Q}}_0$ is the variance covariance matrix of the residuals in our OLS training sample regression. Finally, in the case where σ^2 is allowed to be non-zero, for the inverted gamma prior for σ^2 we set $a_0 = 1$ and s^2 equal to the average of NG

22 To see this, recalling the spherical assumption made about $\mathbf{V}$, then the variance covariance matrix of the error term in Equation (A6) takes the form:

$$\begin{aligned}\mathrm{E}\left(\boldsymbol{\xi}_t\boldsymbol{\xi}_t'\right) &= \mathbf{W}_t\mathrm{E}\left(\mathbf{uu}'\right)\mathbf{W}_t' + \mathrm{E}\left(\mathbf{E}_t\mathbf{E}_t'\right) = \mathbf{W}_t\left(\boldsymbol{\Omega}\otimes\sigma^2\mathbf{I}_{\mathrm{NGP}}\right)\mathbf{W}_t' + \boldsymbol{\Omega} = \sigma^2\mathbf{X}_t'\mathbf{X}_t\boldsymbol{\Omega} + \boldsymbol{\Omega} \\ &= \left(1 + \sigma^2\mathbf{X}_t'\mathbf{X}_t\right)\boldsymbol{\Omega} = \sigma_t\boldsymbol{\Omega}\end{aligned}$$

individual variance estimates obtained from simple AR (2) regressions estimated for each variable. These prior choices largely follow Canova *et al* (2007).

Information from the data can be summarised by the kernel of the likelihood function for the SUR form of the model:

$$L \propto \left(\Pi_{t=1}^{T} \sigma_t^{-\frac{\mathrm{NG}}{2}} \right) |\mathbf{\Omega}|^{-\frac{T}{2}} \exp\left[-0.5\Sigma_{t=1}^{T} \left(\mathbf{Y}_t - \boldsymbol{\chi}_t \boldsymbol{\theta} \right)' \left(\sigma_t \mathbf{\Omega} \right)^{-1} \left(\mathbf{Y}_t - \boldsymbol{\chi}_t \boldsymbol{\theta} \right) \right] \tag{A9}$$

Combining the prior information with the likelihood does not offer an analytical solution for joint posterior distribution of parameters. Therefore we used Monte Carlo Markov Chain (MCMC) techniques to simulate the posterior distribution. Since analytical expressions for the conditional posterior distributions of $\boldsymbol{\theta}$ and $\mathbf{\Omega}$ do exist given our semi-conjugate choice of prior, we employ the Gibbs sampler. However, the conditional posterior distribution of σ^2 is non-standard and a Metropolis step is used within the Gibbs loop to obtain the correct posterior distribution. The steps in the estimation process are as follows.

1. Given starting values for σ^2 and $\mathbf{\Omega}$, draw $\boldsymbol{\theta}$ from a normal distribution $f\left(\boldsymbol{\theta} \middle| \mathbf{Y}^T, \mathbf{\Omega}, \sigma^2\right) = \mathrm{N}\left(\boldsymbol{\theta}_T, \mathbf{V}_T\right)$ with mean and variance given by:

$$\mathbf{V}_T = \left(\mathbf{V}_0^{-1} + \Sigma_{t=1}^{T} \frac{\boldsymbol{\chi}_t' \mathbf{\Omega}^{-1} \boldsymbol{\chi}_t}{\sigma_t} \right)^{-1} \tag{A10}$$

$$\boldsymbol{\theta}_T = \mathbf{V}_T \left(\mathbf{V}_0^{-1\prime} \boldsymbol{\theta}_0 + \Sigma_{t=1}^{T} \frac{\boldsymbol{\chi}_t' \mathbf{\Omega}^{-1} \mathbf{Y}_t}{\sigma_t} \right) \tag{A11}$$

2. Given the starting value for σ^2 and the draw of $\boldsymbol{\theta}$ obtained in Step 1, draw $\mathbf{\Omega}$ from an inverted Wishart distribution:

$$f\left(\mathbf{\Omega}^{-1} \middle| \mathbf{Y}^T, \boldsymbol{\theta}, \sigma^2\right) = Wi\left(z_0 + T, \left[\mathbf{Q}_0^{-1} + \Sigma_{t=1}^{T} \frac{\left(\mathbf{Y}_t - \boldsymbol{\chi}_t \boldsymbol{\theta}\right)\left(\mathbf{Y}_t - \boldsymbol{\chi}_t \boldsymbol{\theta}\right)'}{\sigma_t} \right]^{-1} \right) \tag{A12}$$

3. Given the draws for $\boldsymbol{\theta}$ and $\boldsymbol{\Omega}$ obtained in Steps 1 and 2, draw σ^2 employing a Metropolis step. To do this, we evaluate the kernel of the posterior (Equation (A13) below) at a new candidate draw of σ^2 relative to the previous draw. The candidate draw is generated from a normal distribution centred at the previous draw, i.e. $\sigma^2_{cand} \sim \mathrm{N}\left(\sigma^2_{prev}, c\right)$ where we calibrate the variance c to achieve an acceptance rate of between 30 and 50 per cent. The candidate draw is accepted with a probability equal to the minimum of 1 and the ratio of the kernels.[23]

$$f\left(\sigma^2 \middle| \mathbf{Y}^T, \boldsymbol{\theta}, \boldsymbol{\Omega}\right) \propto L\left(\mathbf{Y}^T \middle| \boldsymbol{\theta}, \boldsymbol{\Omega}, \sigma^2\right) \times \mathrm{IG}\left(\frac{a_0}{2}, \frac{a_0 s^2}{2}\right) \tag{A13}$$

4. Repeat Steps 1 to 3 conditional on the most recent draw for the parameters.

5. Check for convergence of the posterior distribution after discarding a burn-in sample to remove any influence of the choice of starting values.

We used 20 000 draws in the Gibbs sampler routine described above to estimate the posterior distribution of the parameters, with the first 10 000 draws discarded as a burn-in sample. To check convergence of the posterior distribution the first and second moments of the coefficient estimates at various points of the chain were compared.

23 More details can be found in Canova *et al* (2007).

Appendix B: Feasible Least Squares Estimation

As discussed in Appendix A, for $\sigma^2 > 0$ the error term in the restricted SUR form of the model is heteroskedastic, with variance given by $\sigma_t\mathbf{\Omega}$ where $\sigma_t = 1 + \sigma^2\mathbf{X}_t'\mathbf{X}_t$. In the version of the model where σ^2 was estimated, the posterior mean estimate of σ^2 was found to be small but away from zero, which suggests there is some evidence of (minor) heteroskedasticity in the errors. Therefore as a robustness check we also estimated the restricted SUR form of the model using feasible least squares and calculated robust standard errors. Table B1 presents *t*-statistics for some of the key coefficients in the model. While there are some differences compared with the Bayesian estimates, qualitatively the results are similar. In particular, the common inflation indicator was still found to be significant in both the headline and core inflation versions of the model and oil price inflation was found to be a significant explanator of headline inflation.

Table B1: Feasible Least Squares Estimation Results

Coefficient *t*-statistics

	Model with headline inflation	Model with core inflation
Inflation equations		
Common inflation indicator	**4.95**	**5.51**
Common real activity indicator	–0.16	–0.06
Oil price inflation	**4.58**	0.32
Non-fuel commodity price inflation	1.62	0.75
Real variable equations		
Common real activity indicator	**2.07**	**1.90**
Oil price inflation	–0.13	–0.16
Non-fuel commodity inflation	**2.65**	**2.75**

Notes: Estimation sample is 1981:Q2 to 2011:Q1; *t*-statistics calculated using robust standard errors; numbers in bold indicate significance at the 10 per cent level or lower

Appendix C: Data Sources

Table C1: Data Sources

Series	Source(s)
Consumer price indices for individual G7 economies	OECD.*Stat* (database); Thomson Reuters; quarterly index constructed as the average of the monthly index for the relevant quarter
Consumer price indices excluding food and energy for individual G7 economies	As above
Real GDP, real private consumption and real fixed private investment for individual G7 economies	Thomson Reuters; national sources, March 2011 vintage
Oil and non-fuel commodity prices	IMF International Financial Statistics database, June 2011
US/SDR exchange rate	RBA
Australian consumer price inflation	ABS; RBA
Australian trimmed mean inflation	ABS; RBA
Australian inflation expectations	Norman and Richards (2010); RBA
Australian output gap	Norman and Richards (2010); RBA
Australian unemployment rate	ABS; RBA
Australian import prices	ABS; Norman and Richards (2010); RBA
Australian real unit labour costs	ABS; Norman and Richards (2010); RBA

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