A Multi-Country Structural VAR Model*

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November 2000

Abstract

Traditionally, the VAR literature has focussed on at most two country/region models. A multi-country SVAR highlights the importance of various international influences on a small open economy Using the example of the effects of US and Japanese shocks on the Australian economy we show that incorporating both of these economies as international influences, and accounting for possible multicollinearity between output variables, makes a substantial difference to the amplitude of the impulse responses recovered from the system.

JEL Classification: C51, F41

keywords: structural VAR, open economy, international shocks

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*Part of this project was supported by a La Trobe University Small ARC Grant. We would like to thank Warwick McKibbin, Vance Martin, Adrian Pagan and Peter Summers for comments and discussions.

1 Introduction

There is growing interest in the interdependence between economies. The shift in focus from closed economy to open economy modelling was evident in the Brookings Institute project of the mid 80's (Bryant et al. (1988)). That project included a number of structural equation models and the Minneapolis World VAR model developed by Litterman and Sims. The Minneapolis World VAR was based on three regional blocks of the US, Japan and Europe, and was a first attempt to use VAR methods to link more than two regions.

Subsequent VAR research has concentrated on closed economy and two country open economy models. Multi country models usually involve amalgamating countries into two blocks or regions (for example Monticelli and Tristani (1999)). Consequently it is not possible to analyse the effects of shocks on individual economies.

Substantial policy interest exists in the impact of external shocks on small open economies. To enrich this beyond a two country setting we develop a tri-country SVAR model, using the example of interactions between the US, Japan and Australia. The US and Japan are dominant world players and Australia's largest trading partners.

International influences are important in modelling the Australian economy (Gruen and Sheutrim (1994), Beechey et al (2000)). Although bilateral trade between Australia and Japan is larger than Australia and the US, models of the Australian economy typically include only the US. In the SVAR literature see: Summers (1999), Dungey and Pagan (2000), Brischetto and Voss (1999).

Unlike the Minneapolis World VAR, the current paper estimates a SVAR of interdependent economies simultaneously. The initial specification is based on the concatenation of three Sims (1992) style economies in an unrestricted model. Data limitations mean that the analysis was carried out quarterly.[1]

[1] Fry (2000) examines the implications of shifting from monthly to quarterly data in

At first a large over parameterisation problem exists. This is addressed with block-exogeneity assumptions and causality restrictions on both the contemporaneous and dynamic relationships - the strictly recursive structure of the model means that it is not necessary to adopt the solution algorithms developed in Zha (1999) although they would assist in reducing computing time.

The construction of an international structural VAR model incorporating three economies is generally successful. However, potential multicollinearity problems between the output variables arise, associated with a common world business cycle. This problem is addressed by placing restrictions on the system. In this application, such a restriction produces changes to the estimates - in particular the Australian responses to external shocks are dampened.

The paper proceeds as follows: Section 2 outlines the VAR methodology, Section 3 and 4 outlines the details relating to the estimation and results of the tri-country structural VAR model respectively, followed by some concluding comments in Section 5.

2 Methodology

The VAR methodology is by now well-known; see Hamilton (1994). Briefly, we examine the relationship between a set of endogenous variables, where the data determines the relationship;

$$B_0 y_t = B(L) y_{t-l} + \varepsilon_t \tag{1}$$

where y_t is a vector of variables of interest, the lag length L, is determined by some a priori selection and ε_t are white noise errors. This paper is in the tradition of Sims (1992) and imposes a normalised lower triangular matrix structure on B_0. However, a transfer of the application to the Bayesian environment should prove reasonably straightforward. The reduced form of

the Sims (1992) models.

the above system can then be written as:

$$y_t = A(L)y_{t-1} + e_t \tag{2}$$

where $A = B_0^{-1}B$ and $e_t = B_0^{-1}\varepsilon_t$. It is also useful to recognise that this can be written as a moving average of the error terms:

$$y_t = C(L)\varepsilon_t + \textit{initial values} \tag{3}$$

where the $C(L)$ are impulse response functions from the system. Initially we examine an exactly identified model with zero restrictions only in the upper triangle of B_0. We then move to an overidentified system, with further zero restrictions in the lower triangle of B_0 and in the dynamic relationships specified in $B(L)$. Despite this structure, the model remains strictly recursive.

The procedure MAXLIK in GAUSS is used to maximise the likelihood function for the Structural VAR component of the paper. The BFGS iterative gradient algorithm in MAXLIK is used with the derivatives numerically computed.

Confidence intervals for the impulse response functions can be generated by several methods. Analytical and Monte Carlo style confidence intervals are generally seen to be dominated by the bootstrap after bootstrap approach of Kilian (1998) (Kilian (1999) and Hansen (1999)). However, in this paper we present the Monte Carlo intervals due to empirical difficulties with the application of the bootstrapped results - we are not alone in this finding (Sims and Zha (1999)), and it is a subject of further research.

3 A Tri-Country Structural VAR Model

Sims (1992) estimated a series of VARs for major economies individually, each containing the following variables; world commodity prices, a domestic interest rate, the exchange rate, money supply, consumer prices and industrial production. An SVAR model based on the concatenation of three country specific Sims style models is hampered by over parameterisation. Contemporaneous and dynamic restrictions ease this problem. The main restriction imposed is that of block exogeneity between economies - a small open economy assumption on the part of Australia, and a large open economy assumption on the part of the US. The recent development of multiblock estimation techniques by Zha (1999) should extend this body of literature.

The US economy is an 'anchor' for the system, making it block exogenous to both Japan and Australia. This seems reasonable for the Australian case. In the case of Japan, Selover (1997) and Horiye, Naniwa and Ishihara (1987) support the transfer of the US business cycle to Japan while Selover (1997) refutes the opposite direction. Similarly, the placement of Japan in the centre of the system is consistent with evidence that shocks from Japan are transmitted to Australia, but not vice-versa (Selover and Round (1996)). The Japanese economy is influenced by the US economy, but is block exogenous to the Australian economy. As a small open economy the Australian economy does not feedback into either the US or Japanese economies. This block exogeneity restriction has become relatively common in two country open economy SVAR models recently, following the work of Cushman and Zha (1997).

Each national-economy includes domestic variables on real output, inflation, and the interest rate. GDP outcomes are of policy interest in Australia, and consequently GDP is used as the measure of output in the SVAR. However, industrial production was substituted in Japan due to difficulties with the behaviour of Japanese GDP, see also Horiye, Naniwa and Ishihara (1987). Dungey and Pagan (2000) showed that the inclusion of both domestic GDP and GNE in an Australian SVAR improved its performance as this structure introduces a balance of payments type variable into the economy. GDP is interpreted as a production variable and GNE as domestic demand. The use of inflation, rather than the price level as in Sims (1992), is increasing in the literature; see for example Garratt, Lee, Pesaran and Shin (1999).

Table 1:
Key Variables in the Multi-Country SVAR Model

	Abbreviations			
Variables	Other	US	Japan	Australia
Commodity Price Index	PC			
Domestic Demand				$AGNE$
Production		$UGDP$	JIP	$AGDP$
Inflation		$U\pi$	$J\pi$	$A\pi$
Interest Rate		UR	JR	AR
Exchange Rate			JE	$NTWI$

The international variables are the commodity price index, the Yen per USD exchange rate, and the Australian Nominal Trade Weighted Index (NTWI). We do not include a monetary aggregate as it did not add to our results[2]. Existing Australian VARs use either of the nominal or real TWI indices and as in Eichenbaum and Evans (1995) the choice between nominal and real exchange rate indices produces little difference in the results. Sims's (1992) world commodity price index is a common variable which influences all economies.

Each variable was entered into the model in log levels, with the exceptions of the interest rates and the inflation rates for each country. All data were detrended against a constant and a time trend to allow a variety of growth rates in the variables. Thus, the structural model can be though of as describing the dynamics around a steady state (see Dungey and Pagan (2000) for a similar approach). Table 1 outlines the variables used in the SVAR estimation along with the abbreviation for each variable; sources are given in Appendix A.

The structural VAR was estimated with two lags over the period Quarter 3, 1979 to Quarter 2, 1999 - that is 80 observations. The starting point

[2] The inclusion of monetary aggregates is a contentious issue in the literature, see Sack (2000) and McCallum (1999).

Table 2:

Contemporaneous Structure

	US				Japan				Australia				
	PC	UGDP	Uπ	UR	JIP	Jπ	JR	JE	AGNE	AGDP	Aπ	AR	NTWI
PC	*												
UGDP	*	*											
Uπ	*	*	*										
UR		*	*	*									
JIP	*	*			*								
Jπ	*				*	*							
JR					*	*	*						
JE	*	*	*	*	*	*	*	*					
AGNE									*				
AGDP		*			*				*	*			
Aπ									*		*		
AR									*		*	*	
NTWI	*	*	*	*	*	*	*	*	*	*	*	*	*

reflects the changes in the Australian financial system in the early 1980s. This, coupled with the Clements and Hendry (1998) demonstration of the mis-specification of impulse response functions in the presence of structural breaks, determines our sample period.

3.1 Contemporaneous and Dynamic Structure

The variables enter into each equation as described in Tables 2 and 3 which show the contemporaneous and lag structures of the model respectively. The rows show the dependent variable in each equation, while the columns show the variables appearing in it, as indicated by *. If the variable enters into the equations with all lags, * is recorded. ** is used to indicate if the variable enters the equation with only the second lag present.

Table 3:

Lag Structure

	US				Japan				Australia				
	PC	UGDP	Uπ	UR	JIP	Jπ	JR	JE	AGNE	AGDP	Aπ	AR	NTWI
PC	*												
UGDP	*	*	*	**									
Uπ	*	*	*	**									
UR	*	*	*	*									
JIP	*	*			*	*	**	*					
Jπ	*				*	*	**	*					
JR					*	*	*						
JE	*	*	*	*	*	*	*	*					
AGNE									*	*	*	**	*
AGDP		*			*				*	*	*	**	*
Aπ									*		*	**	*
AR	*								*		*	*	
NTWI	*	*	*	*	*	*	*	*	*	*	*	*	*

The assumption that the US is contemporaneously block exogenous to Japan and Australia, and that Japan is contemporaneously block exogenous to Australia is extended in the structural model to the system dynamics. The only variable assumed to affect the US as determined outside of the domestic economy is the commodity price index.

3.1.1 The Commodity Price Index Equation

Sims (1992) incorporated commodity prices into his models to capture inflationary expectations. Commodity prices also represent the terms of trade effect in the Australian literature: see Gruen and Wilkinson (1994) for example. Commodity prices are self determined, depending only on an AR process in this model. Ideally one would want to allow the commodity prices to fluctuate in response to the economic conditions in the three countries. However, experimentation showed that this introduced too much leakage into the system.

3.1.2 The GDP/Industrial Production Equations

The output equations in each economy contain lagged values of domestic output, inflation, the interest rate and the contemporaneous and lagged commodity price data. The effect of interest rate changes in all economies are further constrained to impact after one lag, in line with the perceived delay of the impact of monetary policy. The Japanese output equation also includes the influence of US output; and the Australian equation includes Japanese and US output data. The international transmission of shocks from the US hence filters to Australia via a direct link and an indirect link via the effect of the shock on the Japanese economy.

3.1.3 The Inflation Rate Equations

The US literature often models inflation using a closed economy approach (for an alternative see Gordon (1998)). Here US inflation is modelled as dependent on the contemporaneous and lagged impact of the commodity price index and domestic output. Other domestic variables enter with a lag (the restriction on the timing of the impact of interest rate changes also applies).

The inclusion of lagged exchange rates in the inflation equation for Australia and Japan represent the impact of import prices (see Gruen, Pagan and Thompson (1999) and Beechey et al. (2000) for evidence for Australia). The commodity price index enters the Japanese inflation equations but not the Australian inflation equation. Commodity prices represent import prices to Japan, and export prices to Australia, and export price inflation is not generally empirically important for Australia (Dungey and Pitchford (2000)).

3.1.4 The Interest Rate Equations

The interest rate represents the monetary policy instrument in this model. This is a contentious area of the literature (see for example the debate between Sims (1998) and Rudebusch (1998a,b)). However, we obtain appropriate monetary policy responses without the need for the inclusion of money supply variables.

The interest rate for each of the countries depends contemporaneously on domestic output and inflation. Monetary policy is determined entirely with respect to domestic economic conditions. We have not imposed a common world interest rate on the model directly although there remain linkages between the international interest rates via the links between output in each economy. For the US and Australia, the commodity price index enters into this equation on a lagged basis, as monetary policy adjusts to the effects of export prices on output after a lag.

3.1.5 The Exchange Rate Equations

Each of the exchange rates is modelled to include all available information in the system; so the Yen rate equation includes all US and Japanese variables in the model and the commodity price index. All foreign and domestic variables enter into the Australian NTWI. Two dummies have been included in the NTWI equation, as in Dungey and Pagan (2000).[3]

3.2 Issues of Multicollinearity

The results for this first attempt at constructing a tri-country structural VAR model are pleasing. However, there are potentially multicollinearity problems. Consider the task of a single equation estimation of Australian

[3]These dummies are in place to account for two data outliers. This first occurs in Quarter 2, 1985 when the cash rate jumped 300 basis points. The second occurs in Quarter 3, 1986 to account for the effects of the Banana Republic statement made by the then Treasurer of Australia, Paul Keating.

GDP, such as in Gruen and Sheutrim (1994). One would not generally write such an equation as including both Japanese and US output as independent variables, as multicollinearity would immediately be suspected due to some form of common international business cycle. In this section we consider potential multicollinearity between US GDP and Japanese industrial production in the Australian GDP equation. No other equations suffer from this potential problem.

Concern over multicollinearity arises due to our interest in the impact of, say, a US interest rate shock, on Australian output. In the proposed system that impact will come about through the effect of the change in US GDP on Australian GDP, and the subsequent effect of the change in Japanese industrial production on Australian GDP. For policy purposes it is of interest to analyse the relative size of these two effects.

The proposed solution is to place a further constraint on the system. Single equation estimates such as Gruen and Sheutrim use some measure of total international output as the independent variable in estimating Australian GDP. Hence we construct a weighted sum of an index of US GDP and Japanese industrial production to replace these variables in the Australian component of the model. An identity is added to the model (formally placed prior to the equation representing AGNE in Tables 2 and 3) comprising $GDPTOT = w_1 UGDP + w_2 JIP$ where the weights represent the relative common currency values of US and Japanese GDP in 1990. Here, $w_1 = 0.729$ and $w_2 = 0.271$. To facilitate comparisons with the unrestricted system, US GDP and Japanese industrial production are defined as the weighted indices; so that GDPTOT will take the value 100 in the base year.[4]

[4] To implement this restriction we construct an identity $UGDPTOT = \omega_1 UGPD + \varpi_2 JIP$ and estimate the VAR with $AGDP$ dependent on $UGDPTOT$ with loading β. Hence a shock to UGDP is transmitted through UGDPTOT with weight ϖ_1. To assess the impact of this shock on $AGDP$ requires us to replace the zero coefficient for $UGDP$ as shown in Tables 2 and 3 with the coefficient $\beta\varpi_1$. Similarly the coefficient for JIP in the $AGDP$ equation is replaced with $\beta\varpi_2$ in calculating impulse response functions. This is a manipulation to produce impulse response functions, not the method of estimation.

The effect of this constraint on the system is to alter the form of the resulting impulse response functions. The change in Australian GDP resulting from a shock to the US output equation in the original system can be expressed as: $\frac{\partial AGDP_t}{\partial \varepsilon_{US,t}} = \frac{\partial UGDP_t}{\partial \varepsilon_{US,t}} + \frac{\partial JIP_t}{\partial \varepsilon_{US,t}}$ whereas in the restricted system this change is: $\frac{\partial AGDP_t}{\partial \varepsilon_{US,t}} = \frac{\partial AGDP_t}{\partial GDPTOT_t} \quad \frac{w_1 \partial UGDP_t}{\partial \varepsilon_{US,t}} + \frac{w_2 \partial JIP_t}{\partial \varepsilon_{US,t}}$. In the instance where multicollinearity is non-existent these two expressions will give the same result. We find that this restriction has an important impact on the results. The following section explores the estimated results, and points out the differences inherited from incorporating the multicollinearity restriction.

4 Results

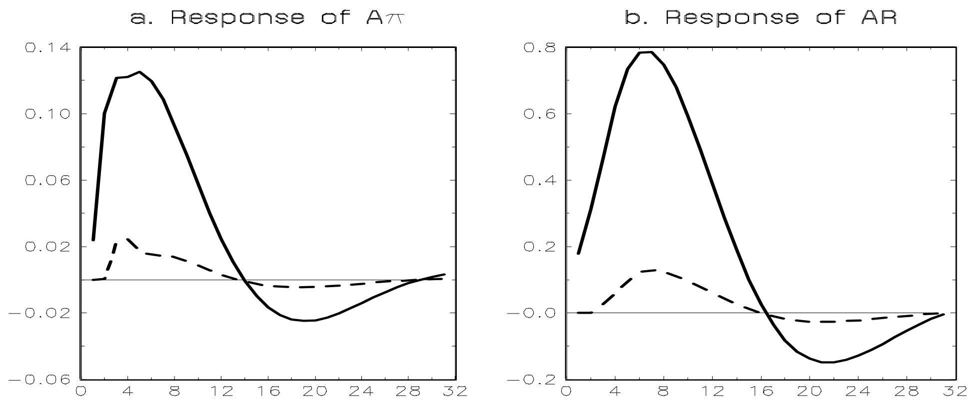
Table 4:

Standard Deviations for the Multicountry Model

US		Japan		Australia	
PC	0.038			$AGNE$	0.011
$UGDP$	0.004	JIP	0. 004	$AGDP$	0.005
$U\pi$	0.546	$J\pi$	0. 676	$A\pi$	0.589
UR	0.876	JR	0. 555	AR	1.120
		JE	0. 040	$NTWI$	0.032

A selection of the key impulse response functions generated are discussed in this section. The full set of responses is available from the authors on request. Appendix B displays the figures presented in the text of this paper along with their corresponding 95% confidence intervals for the three year period following the shock. As with most VAR applications, the confidence intervals are very wide, and including them in the text would inhibit discussion. The size of the shocks are given by the standard deviation of the errors in Table 4.

Figure 1: Shock AGNE/AGDP: Solid line - AGDP, dashed line - AGNE

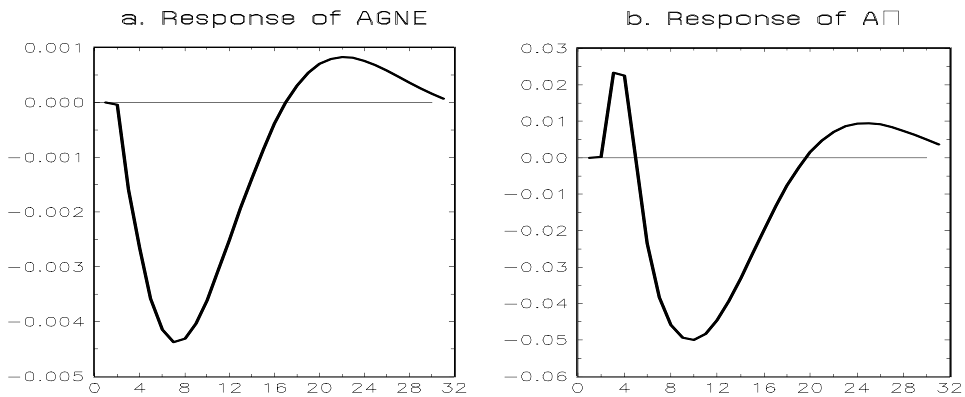


4.1 Shocks to the domestic economy

None of the shocks to the Australian economy feedback into the international component of the model due to the small open economy assumption. The behaviour of the model in response to domestic economy shocks is very similar to that observed in Dungey and Pagan (2000). Both AGNE and AGDP shocks result in higher inflationary outcomes (Figure 1a - note that the size of the AGDP and AGNE shocks differ) and subsequent increases in the domestic interest rate as monetary policy contracts (Figure 1b).

A cash rate (monetary policy) shock has the expected contractionary effect on domestic output and inflation (Figures (2a and 2b)). There is some initial evidence of the price puzzle in the domestic economy as inflation initially rises, but this is statistically insignificant. Neither the inclusion of the commodity price variable nor a money supply variable (not reported here) solved the price puzzle, contrary to the arguments made by Cochrane (1998) and McCallum (1999) respectively. A similar short-lived price puzzle was overcome in Dungey and Pagan (2000) with the inclusion of international equity market variables. However, Brooks and Henry (2000) show that the

Figure 2: Shock AR



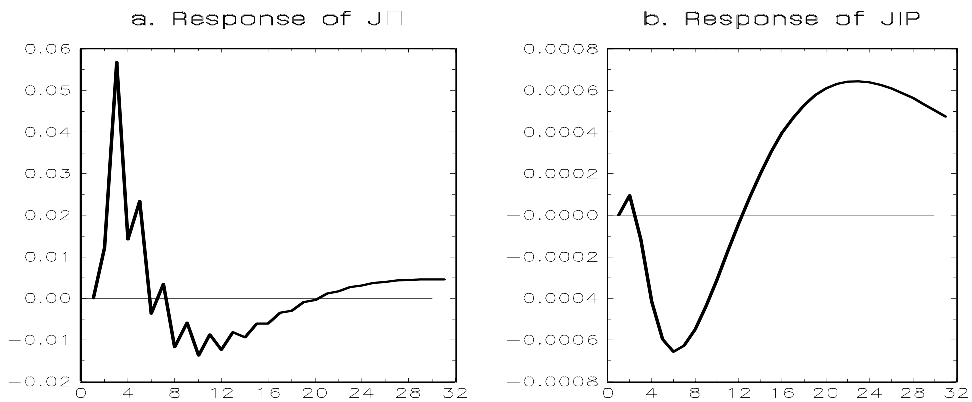
equity links for the three countries considered here are not causal.

4.2 Shocks to the international economy

The primary focus of this paper is on the transmission of international shocks to the domestic economy. The current model has several sources of such shocks; international commodity price shocks, US sourced shocks and Japanese sourced shocks. The recursive structure of this model makes it useful to discuss the country shocks in reverse order. The commodity price shocks will be discussed in Section 4.3.

The Japanese module of the system behaves similarly to the Australian module in that the Japanese responses to Japanese shocks are in the expected directions. However, the inflation responses to various shocks are generally not smooth. Several experiments with different data sources were conducted with no improvement over the current version. McCallum (1999) argues that the money base needs to be included in macroeconomic models for Japan to provide a better indication of the overall status of Japan's economy. This proved not to be the case here. The behaviour of Japanese inflation is difficult to capture as illustrated by the response of Japanese inflation to an interest rate (monetary policy) shock. Figure 3a shows that the

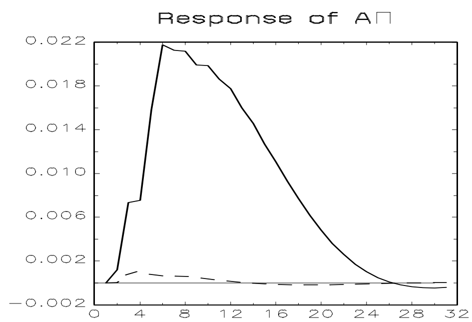
Figure 3: Shock JR



price puzzle is evident in this economy. Despite this, the remainder of the responses to the Japanese interest rate shock are as anticipated, including a reduction in Japanese industrial production (Figure 3b) and an appreciation of the Japanese exchange rate. This result is not uncommon in the Japanese literature; Suzuki (2000) presents similar results. Shioji (1997) finds some reduction in the Japanese price puzzle using oil prices in the place of commodity prices, but in the interest of maintaining degrees of freedom we do not pursue that here.

The impact of Japanese shocks on the Australian economy is also as expected. Given that Japan is a major importer of Australian output, a rise in Japanese output (demand) has a positive impact on Australian output. The impact of a Japanese output shock on Australian inflation is greater than the equivalent Australian demand shock, calculated by producing a similar shock to Australian GDP (Figure 4). Similarly, a shock to Japanese inflation has an effect on Australian inflation through its effect on Japanese output. Shocks to Japanese monetary policy (interest rates), have a contractionary impact on the Australian economy through the output effects and dynamics of the model.

Figure 4: Output Shock: Solid line - Japan, dashed line - Australia



The US component of this model also has desirable responses to its own domestic shocks. US output shocks result in increased US inflation, and a corresponding increase in US interest rates. An unanticipated US monetary policy shock, as modelled by a shock to the US interest rate, induces a reduction in US inflation and a contraction in the US economy. There is no evidence of the price puzzle in the US.

The impact of the US shocks on the Japanese economy is also as anticipated. US output shocks cause a rise in Japanese output, and a subsequent rise in Japanese inflation and interest rates. The effects of a US output shock on US, Japanese and Australian output and inflation are shown in Figures 5a and 5b.

The Australian responses to US sourced shocks are augmented by their transmission through the Japanese economy. The total effects are as anticipated. A positive US GDP shock results in a rise in Australian output (Figure 5a), GNE, inflation (Figure 5b) and subsequently cash rates. An increase in US inflation increases the inflation rate in Australia, primarily through import prices (proxied by exchange rate effects as outlined in Section 3.1.3). A tightening in US monetary policy, through a rise in US interest rates results in lower output in the US, and subsequently Japan and Australia; (Figure 6).

Figure 5: Shock UGDP: Solid line - US, dashed line - Japan, dotted line - Australia

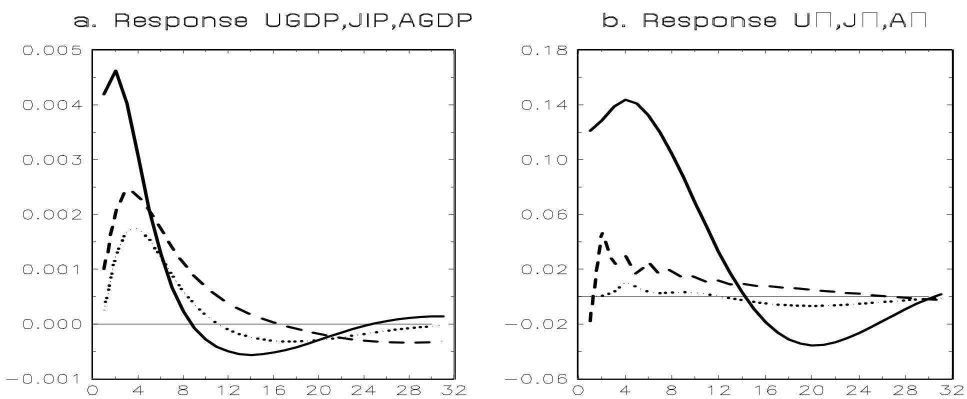


Figure 6: UR Shock: Solid line - US, dashed line - Japan, dotted line - Australia

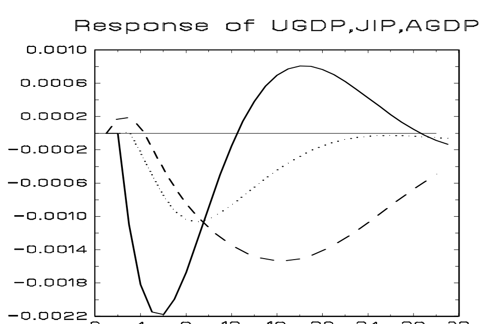
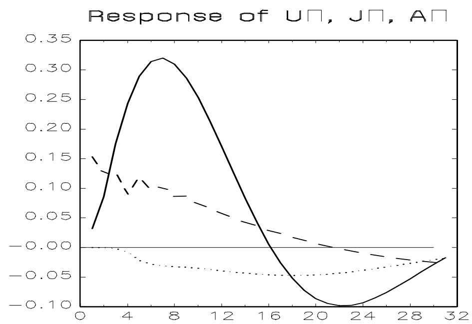


Figure 7: PC Shock: Solid line - Uπ, dashed line - Jπ, dotted line - Aπ



4.3 Shocks to the Commodity Price Index

The result of shocks to the commodity price index in this model are as anticipated. An increase in commodity prices causes an initial increase in US output and subsequently inflation and Cash Rates. The increase in US output results in an increase in Japanese output. Given that commodities are an important import for Japan, the initial inflationary effect is greater for Japan than the US. Japanese inflation continues above trend for 5.5 years, compared with 4 years for the US as shown in Figure 7. Japanese activity begins to decline 2 years after the initial shock, some 9 months before the US economy.

The Australian NTWI appreciates strongly in response to the higher commodity prices, in line with the large literature detailing the strong positive relationship between the Australian currency and terms of trade (see for example; de Brouwer and O'Reagan (1997), Gruen and Wilkinson (1994)). The Australian economy responds positively to the commodity price shock, as exports and hence domestic incomes increase.

One unexpected result from this model is that the higher commodity prices are not reflected in higher Australian inflation (Figure 7). This may partly reflect that the commodity price index used is not a good indicator for inflationary expectations in Australia. Further, although Australia is a large commodity exporter, it is also generally a price taker on international markets, where contracts are primarily written in USD or Yen terms. Hence in this instance, the addition of the commodity price index has not solved the price puzzle, but instead transferred it to another segment of the model.

Thus far the results presented are from the restricted system corrected for potential multicollinearity. The next section briefly discusses the impact of this restriction.

4.4 The impact of the multicollinearity restriction

Without the multicollinearity restriction many of the impulse responses show similar responses to a US-Australia only system (which will be discussed further in Section 4.5); for example, the responses of Australian GDP and Australian inflation to a US GDP shock are shown in Figures 8b and 8d for the US-Australian system, and the three country system with and without the multicollinearity restriction. (Note in the figures that mcc denotes the mulitcollinearity corrected responses, no mcc denotes the responses without the multicollinearity correction, and US-AU denotes the model estimated without Japan.) The multicollinearity restriction tends to dampen responses. Initially this seems counterintuitive given that one would expect Japanese demand to be cumulative with US demand. The answer lies in the sample period, during which Japan has been out of business cycle alignment with the US, and has experienced lower growth. Hence, the Japanese influence tends to dampen the US shocks. The multicollinearity restriction also dampens the responses of variables to a commodity price shock. For example, Figure 9a shows the responses of Australian GNE.

One exception to the above observation is the NTWI responses to various shocks. In general, these responses shift with the addition of Japan to the US-Australia model but do not change much when the multicollinearity restriction is added (Figure 9b for example). This is to be expected, given

Figure 8: UGDP Shock: Solid line - mcc, dashed line - no mcc, dotted line - US-AU.

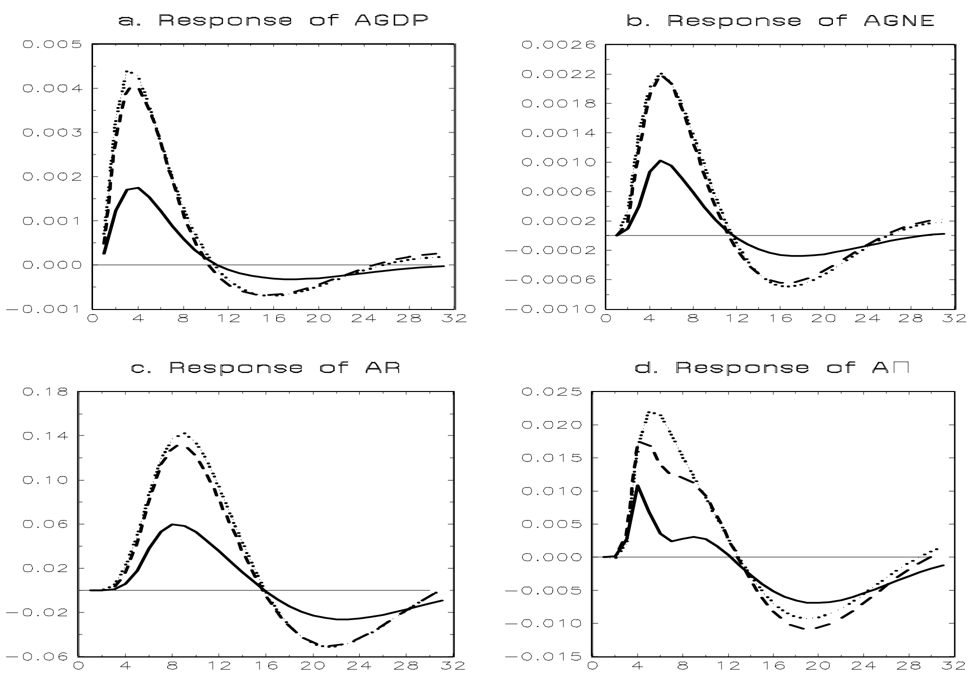
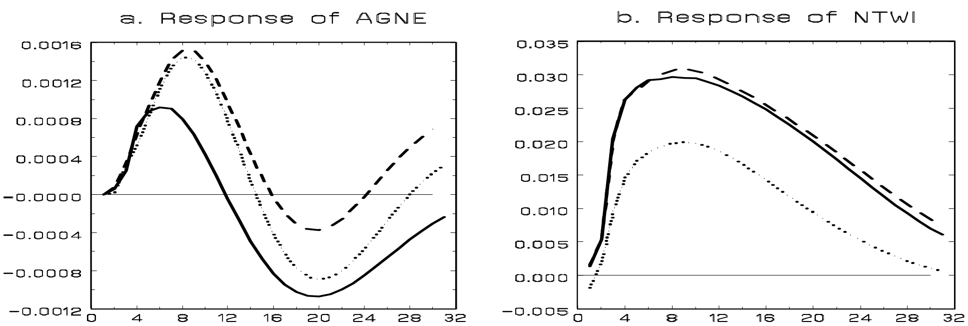


Figure 9: PC Shock: Solid line - mcc, dashed line - no mcc, dotted line - US-AU.



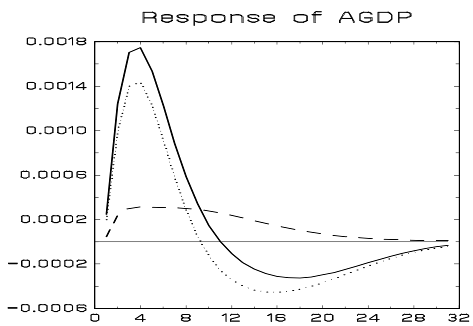
that the exchange rate is measured as a trade-weighted index.

4.5 The contribution of Japan versus the US:

In most Australian macro modelling the international economy is proxied by the US; e.g. Dungey and Pagan (2000), de Brouwer and O'Reagan (1997), and Summers (1999) despite the status of Japan as an equivalently important trading partner. (An exception is the suite of models associated with Warwick McKibbin; see for example McKibbin and Wilcoxen (1999)). In this section we examine some of the effects of omitting Japanese influences.

Recall that the reduced form of the VAR can be expressed as a moving average as in equation (3). Consider a shock to $\varepsilon_{UGDP,t}$ with final impact on Australian GDP denoted by U_T. A shock to $\varepsilon_{UGDP,t}$ has an impact on Japanese industrial production given by the impulse response function as in the previous section, denote this U_J. In this instance the initial impact of the 0.003 unit US GDP shock on Japanese industrial production is 0.001. The effect of a shock to $\varepsilon_{JIP,t}$ on the Australian economy is also known from the impulse response functions, denote this J_A. To assess the effect of the US GDP shock on Australia we first scale the shock to $\varepsilon_{JIP,t}$ to be 0.001; the same as the initial impact of the US GDP shock on Japanese

Figure 10: UGDP Shock: Solid line - Total effect, dashed line - JIP effect, dotted line - UGDP effect



industrial production, denote the scaling factor z. The effect of the US GDP shock on the Australian economy, U_A is then obtained from the expression: $U_A = U_T - zJ_A$.

The results of this process are shown for the effects of shocks to US GDP on Australian GDP in Figure 10. It is evident that the US component of the shock is dominant. The effect of the transmission through the Japanese economy is relatively small. However, despite the small impact of the Japanese transmission effect, the inclusion of the Japanese economy in the system substantially effects the point estimates of the impulse response functions. This is supported by likelihood ratio tests of the hypothesis that the Japanese variables in the Australian component of the model are jointly insignificant. This test was rejected at the 0.05 level of significance when performed in comparison to both the multicollinearity corrected model, and the non-multicollinearity corrected model as shown in Table 5.

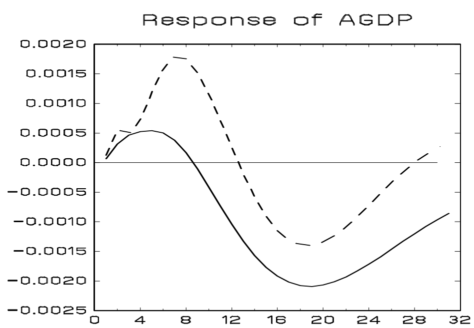
Consider a comparison between a model containing only the US and Australian economies (and the commodity price index variable) with the tri-country model. In general, the addition of the Japanese economy coupled with the multicollinearity restriction reduces the amplitude in the responses of the Australian GDP and GNE to US shocks (Figures 8a and b). The

Table 5:
Likelihood Ratio Tests that Japan is Jointly Insignificant in Australia

	LR Test	p-value
Multicollinearity Corrected Model	29.822	0.012*
Non-Multicollinearity Correct Model	29.560	0.013*

* denotes significance at the 0.05 level
** denotes significance at the 0.01 level

Figure 11: PC Shock: Solid line - US-Australia only, dashed line - full model.

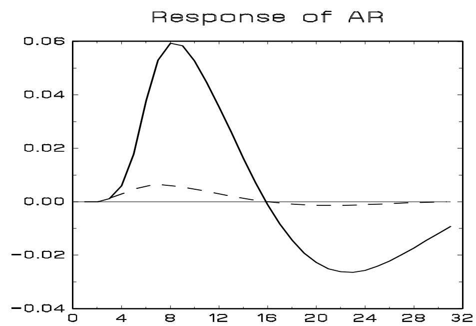


inflation response is virtually the same for the first year in each case (Figure 8d), reflecting the lags in the system. However, the longer term inflationary effects of an international shock will be overstated if the Japanese economy is not included. Consequently, the amplitude of the monetary policy response will be lower in the model which includes Japan than that which does not (Figure 8c).

These results may help explain the better than expected inflationary outcomes from commodity price shocks in recent history. Consider the impact of a commodity prices shock in both systems. Figure 11 shows how the inclusion of Japan in the system mutes the results of a commodity price shock compared with the US-Australia only system.

One further decomposition is included in this section. To examine the impact of international events on domestic monetary policy, we consider the

Figure 12: GDP Shocks: Solid line - UGDP shock, dashed line - equivalent AGDP shock



response of the Australian Cash Rate to a US GDP shock. This represents the combined effect of international and domestic responses.

Figure 12 shows the Australian cash rate response to a domestic output shock. To isolate the domestic response, the domestic output shock is scaled to be the same as the initial impact of the initial US GDP shock on Australian GDP. In effect, we are looking at the difference between the response of the Australian Cash Rate to a purely domestic sourced output shock, and the same size shock resulting from a US GDP shock. The difference shown in Figure 12 is indicative of both the contemporaneous and feedback effects of international shocks in the model, and can be interpreted as the impact of international conditions on monetary policy. This is not the same as stating that the international economy directly increased Australian Cash Rates, as our model precludes this and allows the Australian Cash Rate to react only to domestic conditions. Instead, the decomposition gives a taste of the relative importance of the flow on effects of international economic conditions to the domestic economy and hence domestic monetary policy.

5 Conclusions

The development of a tri-country SVAR model is a contribution to a literature which typically only examines two economies or regions. We develop a method of exploring the interactions of three economies, using the US, Japan and Australia as our sample. Australia is modelled as a small open economy influenced by both the US and Japan, while Japan is influenced by the US. There are no feedback effects from Australia to the US and Japan, or from Japan to the US.

The SVAR model is an overidentified recursive system, with block exogeneity restrictions and structure in both the contemporaneous and lag coefficient matrices. The model is estimated by maximum likelihood, the recursive structure meaning that the problems noted by Zha (1999) are not crucial.

A further restriction was imposed to account for possible multicollinearity between the business cycles of the US and Japan in modelling the effects of changes to output on the Australian economy. This restriction was found to be important - without it the model tends to produce impulse responses which overstate the impact of external shocks on the Australian economy. The relative contribution of US shocks transmitted to Australia via Japan is quite small. This does not imply that the impact of shocks to the Japanese economy are unimportant; likelihood ratio tests on the joint significance of the Japanese variables in the Australian component of the model support their inclusion.

The inclusion of Japan in the model produces a dampening effect on the size of the impulse response functions - meaning that the model with only the US representing the international economy tends to overstate the impact of international shocks on the Australian economy; particularly the effect of commodity price shocks. This may go some way to explaining recent Australian experience with commodity price shocks.

The model incorporated commodity price shocks as exogenous to all three economies, a structure which has been used since Sims (1992) as a means of overcoming the price puzzle in VARs (Cochrane (1998)). The results suggest that this structure in fact pushes the price puzzle into another section of the model. In a similar vein, McCallum (1999) and others have suggested that money supply variables should be included in macro models to appropriately capture monetary policy. However, we are able to adequately capture monetary policy effects using only interest rate variables, and experiments including monetary aggregates failed to improve the performance of the model.

Given the results of this paper and those in Cochrane (1998) restrictions in VAR modelling can dampen the amplitude of the resulting impulse response functions, particularly with respect to output. It remains to be seen whether this result also holds for other models, such as Monticelli and Tristani (1999), where group wise analysis has been performed to force the problem into a two country mode.

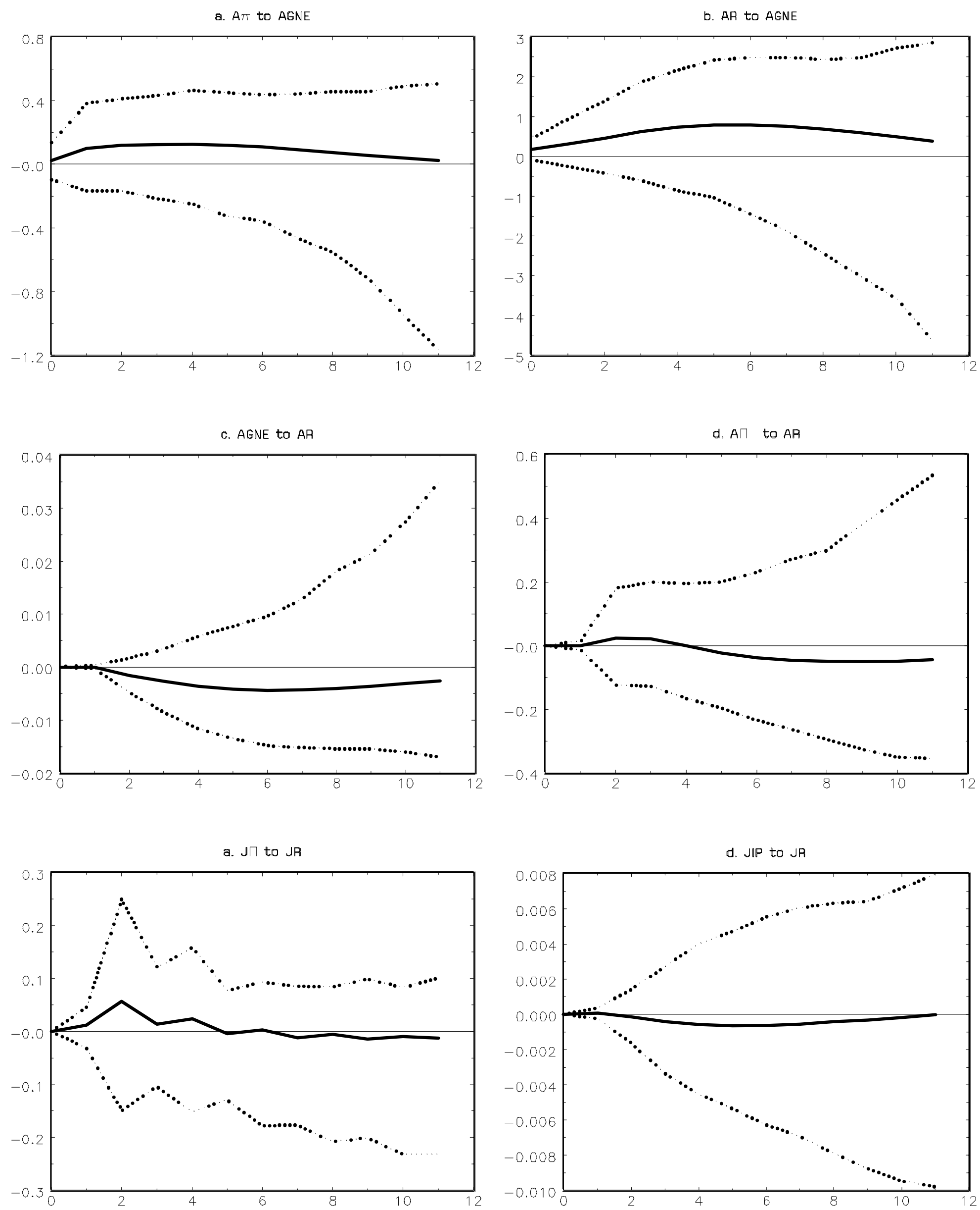
A Data Sources and Database Codes

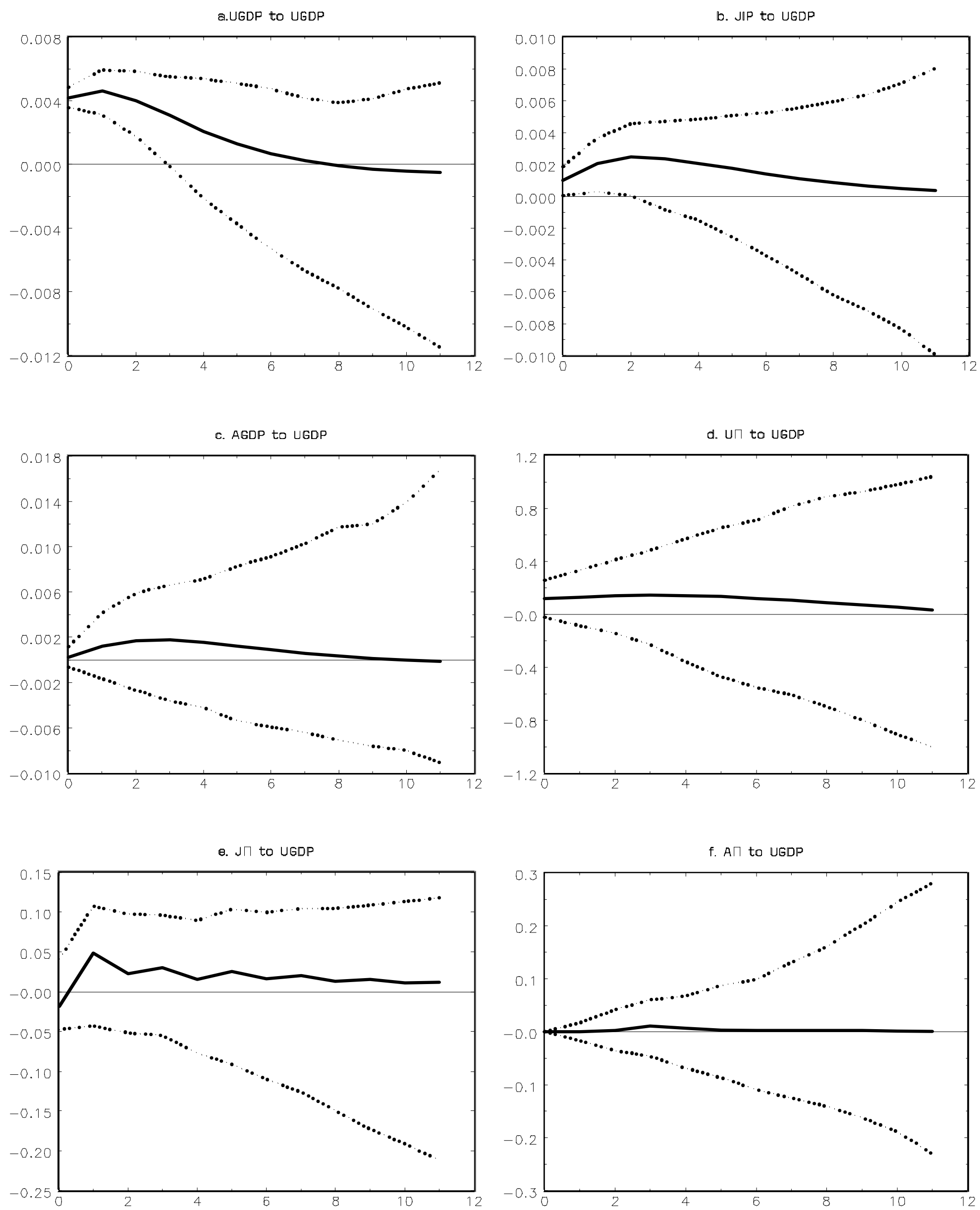
Table 6:

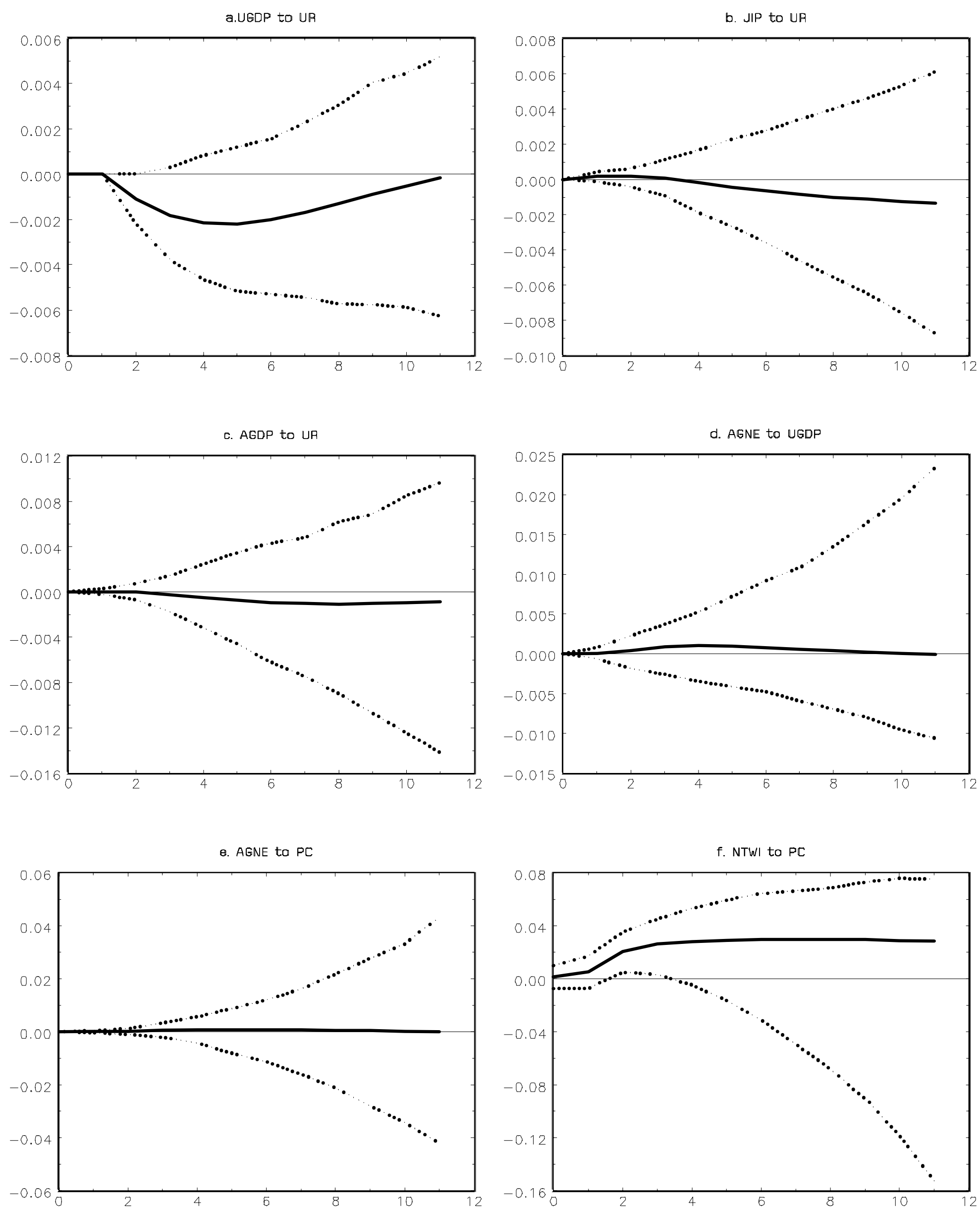
Data: Sources, Codes and Abbreviations.

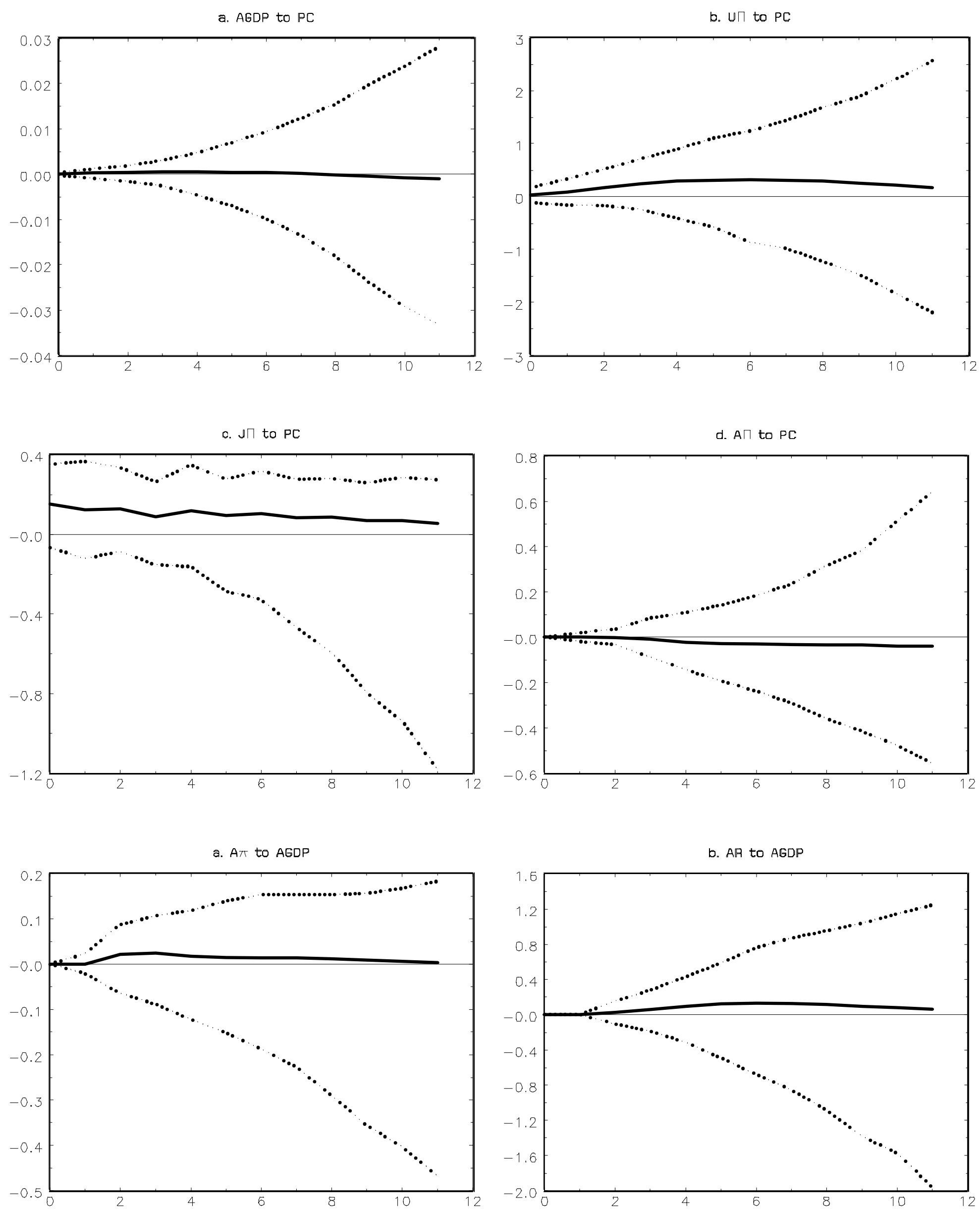
Variable	Source	Code	Abbreviation
Commodity Price Index	Datastream	WDI76AXDF	PC
USA			
Real GDP (SA)	Datastream	USGDP...D	UGDP
Inflation (SA)	Datastream	USI64...F	$U\pi$
Federal Funds Rate	Datastream	USI60B..	UR
Japan			
Industrial Production (SA)	Datastream	JPI66..IF	JIP
Inflation	dX	IOEJPCPI	$J\pi$
Call Rate	Datastream	JPI60..B	JR
USD/YEN	dX	FXRJY, FXRUSD	JE
Australia			
Real GDP (SA)	Datastream	AUGDP...D	AGDP
Inflation	dX	GCPIAGU	$A\pi$
Cash Rate	Datastream	AUCASH11F	AR
Nominal Trade Weighted Index	dX	A8.119aH	NTWI

B Selected Figures and Confidence Intervals




a.UGDP to UGDP
b. JIP to UGDP
c. AGDP to UGDP
d. U□ to UGDP
e. J□ to UGDP
f. A□ to UGDP


a.UGDP to UR
b. JIP to UR
c. AGDP to UR
d. AGNE to UGDP
e. AGNE to PC
f. NTWI to PC



a. AGDP to PC
b. UΠ to PC
c. JΠ to PC
d. AΠ to PC
a. Aπ to AGDP
b. AR to AGDP

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