Centre for Applied Macroeconomic Analysis

The Australian National University

CAMA Working Paper Series **September, 2009**

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CAMA Working Paper 24/2009
http://cama.anu.edu.au

Modelling International Linkages for Large Open Economies: US and Euro Area*

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September 2009

Abstract

Empirical modelling of the international linkages between the Euro Area and the US requires an open economy specification. This paper proposes and implements a structural VECM framework which imposes long run and short run cross-economy restrictions based on theoretically motivated restrictions and empirically supported dominance assumptions. The SVECM distinguishes between permanent and temporary shocks in a system where one cross-economy cointegrating relationship links output levels. In addition, the short run dynamics incorporate both contemporaneous interactions and feedbacks between the two economies. Importantly, greater empirical coherence is obtained by allowing for more direct inflationary effects between the two economies than considered in other recent analyses. Estimated using data from 1983Q1 to 2007Q4, the results demonstrate the cross-country impact of shocks. Although US shocks generally produce stronger effects, nevertheless some shocks originating in the Euro Area have significant effects on the US, particularly for inflation and interest rates.

Keywords: Open Economy Model, Structural Vector Error Correction Model, Euro Area, US
JEL classification: F41, C32

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1 Introduction

Modelling interdependent open economies is both theoretically and empirically challenging. While the theoretical literature has made considerable advances, see for example Corsetti and Pesenti (2005) and the review in Lane (2001), empirical implementation of such models have had less success in convincingly replicating the observed data, see Jung (2007), Justiniano and Preston (2006) and the discussion in Chari, Kehoe and McGrattan (2008).

The problem faced by empiricists is one of identification. Parameters in theoretical simulations are calibrated, but empiricists must determine these from the data - in the case of Bayesians, using suitably informed priors. In addition to the Bayesian approach, two other empirical approaches currently exist. The first is to impose a small open economy assumption; for example Adolfson et al. (2007) treat the US as exogenous to the Euro Area.[1] The second is to use a modular approach where individual countries interact with a rest of world component, and the conjoining of the modules produces a larger whole; the most prominent of these is the global VAR (GVAR) model associated with Dees, di Mauro, Pesaran and Smith (2007), but a three region example also exists in Carabenciov *et al.* (2008).

This paper moves closer to an empirical model of interdependent open economies applied to the US and Euro Area. Identification is achieved by making empirically supported dominance assumptions for a few variables and invoking theoretically motivated exclusion restrictions. Additionally, non-stationarity and cointegration are exploited to further tie the empirical and theoretical structures together, harnessing the identification proposed in Pagan and Pesaran (2009) to differentiate permanent and temporary shocks. The combination of these three approaches results in a model where output and inflation shocks may transmit from either country to the other, while monetary policy remains domestically focussed.

There is a growing body of evidence that world conditions play an important role even for the US economy; see, for example, Ciccarelli and Mojon (2009), Kose, Otrok and Whiteman (2008) Perez, Osborn and Artis (2006), or Dees, di Mauro, Pesaran and Smith (2007). However, the majority of the evidence continues to suggest that the influence of the Euro Area on the US is more limited than the influence of the US on the Euro Area; see Perez, Osborn and Artis (2006) on output, Galesi and Lombardi (2009) on inflation and Erhmann and Fratzscher (2005), Erhmann, Fratzscher and Rigobon (2005) on financial markets and the transmission of real shocks into these markets. In light of this we identify US output and inflation shocks as dominant. However, this does not mean that the US

[1] In many cases this is a completely justified assumption, for example the DSGE model of Lubik and Schorfheide (2007) and the SVAR of Cushman and Zha (1997) for Canda both treat the US as exogenous.

evolves exogenously from the Euro Area; cointegration links output in the two regions in the long run and we also provide a mechanism for feedbacks between them. In this manner the bidirectional relationships between the two are captured.

This paper takes a New Keynesian perspective in order to implement a Structural Vector Error Correction Mechanism (SVECM) that recognises the links between the two major economic entities in the developed world, namely the US and the Euro Area The approach is distinct from the DSGE-VAR framework of Del Negro and Schorfheide (2004) and Del Negro, Schorfheide, Smets and Wouters (2007) applied to closed economy US and Euro Area data respectively [2]. The empirical restrictions applied in this paper are based on interdependent economies in an open economy modelling setting, where one economy (the US) is dominant as the source of output shocks, but dynamic transmissions occur in both directions. However, we find the empirical coherence of the model requires allowing for international inflation effects, which we implement through foreign inflation entering the Phillips curve relationship for each economy. Subsuming foreign inflation effects into the exchange rate, as implied by many theoretical models, provides an inadequate description of the data. An implication of our empirical results is that a theoretical framework is required that more directly accounts for the influence of foreign inflation.

The modelling approach implemented here provides an intepretable set of both long run and short run restrictions on the relationships between variables within and between each economy. More specifically, the SVECM framework recognises that cointegration between variables provides extra identification restrictions (Pagan and Pesaran, 2009), allowing for both permanent and transitory shocks. The Euro Area and the US are allowed to interact both through short run restrictions and long run relationships. The short run restrictions represent international business cycles as in a standard SVAR and allow foreign output effects to enter the Phillips curve, as implied by recent theoretical open economy models (for example, Woodford, 2007). The long run relationship gives rise to an additional feedback mechanism between the two countries via the error correction parameters. Thus the open economy relationships between the Euro Area and the US are captured more consistently with the observed data, in line with Justiniano and Preston (2008).

The application to the Euro Area and the US covers the period 1983Q1 to 2007Q4. Monetary integration in Europe has been tangible during this period through the development and operation of the European Monetary System. In the US, the period covers the post-Volker period where the

[2] Empirical implementations of New Keynesian models have been criticised for the similarity of their deep parameter estimates across multiple countries despite differing data characteristics, and their relative failure to replicate important characteristics of the data, particularly the observed output correlations between countries; see Smets and Wouters (2005), Lubik and Schorfheide (2005) and Justiniano and Preston (2006).

monetary policy regime is stable. The key empirical results in the paper are that the model finds plausible feedback between the US and Euro Area output equations, and produces impulse responses where shocks originating in both economies have significant impacts on key variables. In line with previous empirical findings, US effects are stronger for the Euro Area than vice versa, although the impact on the US is not neglibible.

The structure of the paper is as follows. Section 2 places the problem of interdependent economies where one economy is dominant in the framework of recent open economy literature. This provides the theoretical structure for the econometric specification of the SVECM model outlined in Section 3. Following a brief discussion of the data we use in Section 4, Section 5 contains our substantive empirical results. Finally, Section 6 concludes.

2 Economic Framework

Theoretical analyses of the impact of globalization on the slope of the Phillips curve stress the role of the foreign output gap, as in for example, Woodford (2007). In a two country setting, this implies the presence of cross-economy feedback effects, whereas empirical testing has largely ignored such feedbacks. Empirical examples include Borio and Filardo (2007), Ihlig, Kamin, Lindner and Marquez (2007), and Milani (2009). Further, although the equilibrium conditions implied by the theoretical models involve cross-country relationships for output and other variables (Binyamini and Razin, 2008, Woodford, 2007), these are are ignored in empirical applications, and univariate filtering methods are employed to eliminate "trend" effects.

The framework of this paper, outlined in the following two subsections, aims to incorporate more fully the implications of the theoretical models by allowing two-way interactions between the US and the Euro Area and by capturing "gap" variables in a way that recognizes long run international linkages. However, some identification assumptions above the New Keynesian theoretical models are still needed. Specifically, the SVAR model also requires a minimum number of assumptions about the dominance of one economy over the other in terms of contemporaneous cross-country influences.

2.1 Short Run Model

Consider a SVAR model described by:

$$\widetilde{B}(L)\widetilde{Y}_t = b_0 + \varepsilon_t \tag{1}$$

where, in our two economy case, $\widetilde{Y}_t = (\widetilde{y}_t^{US},\, \widetilde{y}_t^{EA},\, \pi_t^{US},\, \pi_t^{EA}, r_t^{US},\, r_t^{EA},\, q_t)'$ in which $\widetilde{y}_t^i, \pi_t^i$, and r_t^i represent the output gap, inflation, the short run interest rate, respectively for each economy ($i = US$, EA), while q_t is the bilateral (log) real exchange rate (US dollars per one euro), L is the lag operator and ε_t is a (7×1) vector of shocks with diagonal covariance matrix. Our choice of variables is indicated by the conventional New Keynesian framework, which considers an output equation, a Phillips curve and a monetary policy reaction function, with the real exchange rate acting as one international link.

Now write $\widetilde{B}(L) = \widetilde{B}_0 + \widetilde{B}_L(L)$ in (1), where $\widetilde{B}_0$ contains the contemporaneous coefficients and $\widetilde{B}_L(L)$ all lags. Then an SVAR representation of a conventional open economy New Keynesian model has

$$\widetilde{B}_0 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ b_{21}^0 & 1 & 0 & 0 & 0 & 0 & 0 \\ b_{31}^0 & b_{32}^0 & 1 & 0 & 0 & 0 & 0 \\ b_{41}^0 & b_{42}^0 & 0 & 1 & 0 & 0 & 0 \\ b_{51}^0 & 0 & b_{53}^0 & 0 & 1 & 0 & 0 \\ 0 & b_{62}^0 & 0 & b_{64}^0 & 0 & 1 & 0 \\ b_{71}^0 & b_{72}^0 & b_{73}^0 & b_{74}^0 & b_{75}^0 & b_{76}^0 & 1 \end{bmatrix} \begin{matrix} \widetilde{y}_t^{US} \\ \widetilde{y}_t^{EA} \\ \pi_t^{US} \\ \pi_t^{EA} \\ r_t^{US} \\ r_t^{EA} \\ q_t \end{matrix} \tag{2}$$

and

$$\widetilde{B}_L(L) = \begin{bmatrix} b_{11}^L & b_{12}^L & b_{13}^L & 0 & b_{15}^L & 0 & b_{17}^L \\ b_{21}^L & b_{22}^L & 0 & b_{24}^L & 0 & b_{26}^L & b_{27}^L \\ b_{31}^L & b_{32}^L & b_{33}^L & 0 & b_{35}^L & 0 & b_{37}^L \\ b_{41}^L & b_{42}^L & 0 & b_{44}^L & 0 & b_{46}^L & b_{47}^L \\ b_{51}^L & 0 & b_{53}^L & 0 & b_{55}^L & 0 & b_{57}^L \\ 0 & b_{62}^L & 0 & b_{64}^L & 0 & b_{66}^L & b_{67}^L \\ b_{71}^L & b_{72}^L & b_{73}^L & b_{74}^L & b_{75}^L & b_{76}^L & 1 \end{bmatrix} \begin{matrix} \widetilde{y}_t^{US} \\ \widetilde{y}_t^{EA} \\ \pi_t^{US} \\ \pi_t^{EA} \\ r_t^{US} \\ r_t^{EA} \\ q_t \end{matrix} \tag{3}$$

with all coefficients in (3) being functions of the lag operator, and the vector of intercepts given by $b_0 = (b_{01},\, b_{02},\, b_{03},\, b_{04},\, b_{05},\, b_{06}, 0)'$. Note that the pairs of equations capturing the evolution of the output gaps, inflation and monetary policy in (1) to (3) are symmetric for the two economies, with the single exception that US output is assumed to enter contemporaneously into Euro Area output, which we denote as the US being dominant for the evolution of the international business cycle, as discussed below. For notational clarity, a single (current or lagged) coefficient is indicated for each variable in these equations, but in practice all coefficients are polynomials in the lag operator, L.

The usual causal ordering applies to output, inflation and interest rates in first six equations of the system. Note also that the variables are ordered by variable type, in contrast to the more typical country ordering imposed in many small open economy models. It is this alternative ordering which leads us to more clearly define the identification assumptions in terms of dominance for particular variables. As evident in (2), the system is triangular in terms of contemporaneous effects.

The only identification restriction imposed on (2) not sourced from theory is the ordering of US output prior to Euro Area output, so that contemporaneous US output effects directly impact Euro Area output, whereas Euro Area output is constrained to not affect US output contemporaneously. This is dominance of US output over Euro Area output, and is supported in the existing empirical evidence that US output is less affected by external factors than the Euro Area (see, for example, Kose, Otrok and Whiteman, 2008, or Perez, Osborn and Artis, 2006). The general structure of these equations is analogous to that used by Carabenciov *et al.* (2008), although the inclusion of foreign output gap effects (together with domestic real interest rates, here captured by inflation and interest rates) arises from theoretical arguments (for example, Woodford, 2007). Some recent SVAR specifications for an open economy, such as Milani (2009), do not include a term in the real exchange rate because they embody the assumption that the law of one price holds. However, as shown by Monacelli (2005), the more realistic assumption of an incomplete exchange rate pass-through introduces such a term for the determination of output.

Additional restrictions are imposed on the triangular structure of (2), reflecting recent theoretical developments in open economy macroeconomic modelling (for example, Clarida, Gali and Gertler, 2002, Monacelli, 2005, Woodford, 2007).

The Phillips curve equations are symmetric for the two economies, with the foreign output gap reflecting the impact of foreign resource utilization on domestic inflation. This is in common with many recent theoretical and empirical analyzes of the impact of globalization on inflation; see, among others, Borio and Filardo (2007), Ihlig *et al.* (2007) and Woodford (2007). These theoretical models do not imply a direct role for (current or past) foreign inflation, due to the law of one price, although Ihlig *et al.* (2007) include import prices in their empirical analysis. The real exchange rate effects we allow in these equations again arise in the presence of incomplete pass-through (Monacelli, 2005). The monetary policy response functions are standard, and embody the usual assumption that monetary policy is set in relation to the domestic conditions, captured by the output gap and inflation.

The final equation closes the short run model. This allows real exchange rate changes to be influenced by the contemporaneous values of all endogenous variables in the model. This is clearly much more general than a UIP or PPP condition, but reflects the role of the real exchange rate in responding to short run movements in monetary and real developments in both economies. This specification also allows for the existence of the exchange rate disconnect as noted in Obstfeld and Rogoff (2000).

2.2 Long Run Model

Equilibrium conditions in theoretical open economy models generally imply that equality between the terms of trade and the ratio of output in the two countries (for example, Clarida *et al.*, 2002). However, allowing for incomplete pass-through, as in Monacelli (2005), the output ratio is a function also of prices in the two economies. Further, being representative agent models, the implied proportionality relationship for output is effectively for output in per capita terms, whereas we model gross output. With these considerations in mind, the long run relationship between the (log) output levels and the (log) real exchange rate is represented as

$$y_t^{EA} = \beta_0 + \beta_1 y_t^{US} + \beta_2 q_t + u_t. \tag{4}$$

There are, however, econometric complications in the use of (4) and hence in obtaining output gap series embodying this relationship that can be used in the short run model of (1). These complications arise from the nonstationary nature of y_t^{EA}, y_t^{US} and q_t, and hence are concerned with the existence and nature of cointegration. Despite such complications, it is inappropriate to employ univariate detrending to create $\widetilde{y}_t^{US}$ and $\widetilde{y}_t^{EA}$, as this implicitly assumes that distinct unit roots occur in each of these series and hence fails to recognise the existence of any long run linkage for cross-country output levels. Therefore, in line with the arguments of Garrett, Robertson and Wright (2006), we wish to employ a decomposition that recognises the relationship in (4), provided the data supports the existence of such a (unique) cointegrating relationship.

To our knowledge, Dees, Pesaran, Smith and Smith (2009) is the only empirical paper to date studying large open economies that constructs output gaps as deviations from cross-country steady-state relationships. Our methodology for implementing the short run model of (1) to (3) in conjunction with the long run relationship of (4), which is discussed in the next section, differs from that of Dees *et al.* (2009), because we recognize the source of unit roots in the nonstationary series alongside the existence of cointegration.

3 Econometric Specification

The issues associated with forming an estimable econometric specification are discussed in the present section. Methodological issues are discussed first, followed by the SVECM specification.

3.1 Methodological Issues

Our discussion first considers issues associated with permanent and transitory shocks, before examining the implications of dominance for our methodogy.

3.1.1 Permanent and Transitory Shocks

The specification of the SVAR of (1) assumes all variables in $\widetilde{Y}_t$ are stationary. However, some observed variables are stationary while others are nonstationary. Therefore, consider the generic representation of an empirical SVAR model containing n nonstationary $I(1)$ variables and k stationary variables, written as

$$G(L)Y_t = \varepsilon_t \tag{5}$$

where Y_t is the $(n+k)$ vector of endogenous variables in the system and $G(L) = G_0 - G_1 L - G_2 L^2....$ Purely for simplicity of exposition, we can assume that the first n elements of Y_t contain the $I(1)$ variables.

Dungey and Pagan (2009) show that, in a cointegration framework, the "gaps" between the observed and permanent components of the nonstationary series are linear combinations of the changes in the corresponding observed series and equilibrium correction terms. If r cointegrating relationships exist between the $I(1)$ variables in (5), this system can be written in SVECM form as

$$B(L)\Delta Y_t = \Pi Y_{t-1} + \varepsilon_t \tag{6}$$

where $B(L) = B_0 - B_1 L - B_2 L^2 - ... - B_p L^p$ and $\Pi = \alpha\beta'$. The matrices β and α have dimensions $([n+k] \times [r+k])$ and have two components. The first r columns of β contain the linearly independent long run cointegrating relationships between the $I(1)$ variables (and hence the final k rows of these contain zeros), with the first r columns of α containing the corresponding adjustment coefficients. The final k columns of α and β correspond to $I(0)$ variables in Y_t and represent a levels effect resulting from transforming the system from levels to the notation of (6); see Dungey and Pagan (2009).

The presence of r cointegrating relationships between the variables implies that the system experiences $(n-r)$ permanent shocks. By definition, shocks corresponding to $I(0)$ variables are transitory, but it is useful to distinguish permanent and temporary shocks in the cointegrating relationship; see Levtchenkova, Pagan and Robertson (1998) and Jacobs and Wallis (2007).

Using the common trends representation, (6) can be written as

$$\Delta Y_t = F(L)B_0^{-1}\varepsilon_t, \tag{7}$$

where $F(L) = I_{n+k} + F_1 L + F_2 L^2 + \ldots$ and $F(1) = F$ is given by

$$F = \beta_\perp \left[\alpha'_\perp B^*(1)\, \beta_\perp\right]^{-1} \alpha'_\perp, \tag{8}$$

where $B^*(L) = I_{n+k} - B_0^{-1}(B_1 L + B_2 L^2 + ... + B_p L^p)$ and the orthogonal components $\alpha_\perp$ and $\beta_\perp$ satisfy $\alpha'_\perp \alpha = 0$, $\beta'_\perp \beta = 0$, and hence $F\alpha = 0$, $\beta' F = 0$. For notational convenience, now assume that the permanent shocks relate to the first $(n-r)$ elements of Y_t, while the remaining $(r+k)$ variables experience only transitory shocks. Then, following Pagan and Pesaran (2009), we can write

$$\Delta Y_t = F(L) B_0^{-1} \begin{pmatrix} \varepsilon_{t1} \\ \varepsilon_{t2} \end{pmatrix}, \tag{9}$$

and for the shocks ε_{2t} to be transitory requires

$$F B_0^{-1} \begin{pmatrix} 0_{(n-r)\times r} \\ I_{(r+k)\times r} \end{pmatrix} = F \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} = 0. \tag{10}$$

Pagan and Pesaran (2009) show that the restrictions in (10) imply that $\boldsymbol{\alpha}_1 = 0$, where $\boldsymbol{\alpha}_1$ is the sub-matrix of adjustment coefficients for the $I(1)$ variables that give rise to the permanent shocks driving the cointegrating relationships. Therefore, this structure permits the inclusion of error correction terms in equations that define the transitory shocks, but precludes them in the case of permanent ones. This is used in the SVECM specification below in order to identify the sources of the permanent shocks relating to the $I(1)$ variables y_t^{US}, y_t^{EA} and q_t.

Also, from (9), the permanent component of Y_t can be written as

$$\Delta Y_t^p = J \varepsilon_t, \tag{11}$$

where $J = F B_0^{-1}$ and $\beta' J = 0$. Note that the rows of J corresponding to stationary variables are zero, because the k stationary variables have a zero permanent component by definition. Given (11), the SVECM can be transformed to a "gaps" form, where the transitory component of the variables are $\widetilde{Y}_t = \left(Y_t - Y_t^P\right)$. Therefore, as in Dungey and Pagan (2009), the transitory/permanent decomposition of (6) can be written as

$$B^*(L)\Delta \widetilde{Y}_t = \boldsymbol{\alpha}^* \boldsymbol{\beta}' Y_{t-1} - \sum_{j=1}^{p-1} B_j^* \Delta Y_{t-j}^P + B_0^{-1} \varepsilon_t \tag{12}$$

where $\alpha^* = B_0^{-1}\alpha$. An important implication of (12) is that the transitory or "gap" variables are correlated with both the error correction terms and also with the changes in the permanent components. Therefore, the application of any prior or arbitrary filter to obtain gap series is likely to induce misspecification, and hence contaminate the errors in the estimated equations. Indeed, (12) further shows that the error correction terms arising from the cointegrating relationships contain information about the transitory components of $I(1)$ variables (Dungey and Pagan, 2009, Pagan and Pesaran, 2009), which is ignored if simple differences of these variables are employed. Therefore, we recognise the implications of (12) by using differences in conjunction with the error correction terms.

One final point concerns the computation of impulse responses. Substituting (11) into (12) leads to

$$B^{*}(L)Y_{t} = \boldsymbol{\alpha}^{*}\boldsymbol{\beta}'Y_{t-1} - B^{*}(L)J\varepsilon_{t} + B_{0}^{-1}\varepsilon_{t}, \tag{13}$$

which can be written in autoregressive-moving average form as

$$G\left(L\right)Y_{t} = J^{*}\left(L\right)\varepsilon_{t}, \tag{14}$$

where $G(L)$ is the same matrix as in (5). Impulse response functions can be computed in the usual way through (14), in which long run effects impact through the J matrix which enters through (13).

3.1.2 Dominance

SVARs, such as (1) are often identified by defining B_0 to have a triangular structure, as in (2) above. When a multi-country model is written as such a triangular system, economic theory may indicate the order of the variables within a country, but theory does not provide information for the ordering across countries. Therefore, if a triangular representation is to be employed, one or more dominance assumptions may be required to complete the causal ordering. However, dominance in the sense we use it does not preclude the existence of feedback effects. From an econometric perspective, our assumption of dominance of one subvector, say Y_t^D, over another subvector Y_t^S implies that contemporaneous values Y_t^D are weakly exogenous for Y_t^S. However, strict exogeneity is *not* implied, since past Y_{t-i}^S $(i > 0)$ can influence Y_t^D.

As in our two-country model, assume that Y_t^D and Y_t^S are both scalar and consider a common information set Ω_t for the variables $(Y_t^D\ Y_t^S)'$. In a conventional SVAR specification, this information set will be the lagged values of all variables in the model, together with contemporaneous values of variables that are prior to both Y_t^D and Y_t^S in the causal ordering. A dominance assumption is required when the conditional covariance matrix

$$cov\begin{bmatrix} Y_t^D \,|\, \Omega_t \\ Y_t^S \,|\, \Omega_t \end{bmatrix} = \begin{bmatrix} \sigma_D^2 & \sigma_{DS} \\ \sigma_{DS} & \sigma_S^2 \end{bmatrix} \tag{15}$$

has cross-economy covariance $\sigma_{DS} \neq 0$. Applying the Cholesky decomposition to the covariance matrix in (15), it follows that[3]

$$cov\left[\begin{array}{c} Y_t^D \,|\, \Omega_t \\ Y_t^S \,\big|\, \Omega_t, Y_t^D \end{array}\right] = \left[\begin{array}{cc} \sigma_D^2 & 0 \\ 0 & (1-\rho_{DS}^2)\,\sigma_S^2 \end{array}\right] \tag{16}$$

where $\rho_{DS} = \sigma_{DS}/(\sigma_D\,\sigma_S)$ is the conditional correlation in (15).

It is clear from (16) that the assumption that one economy dominates another for a specific variable reduces the variance of the resulting shock for the subordinate variable Y_t^S. Depending on the cross-economy conditional correlation ρ_{DS}, the reduction could be substantial. As is well known from the SVAR literature, the dominance assumption made may affect the resulting impulse response functions, since any shock applied to Y_t^D immediately feeds through to Y_t^S.

Our SVECM specification includes both permanent and transitory shocks, and some further elaboration of the implications in the case of permanent shocks may be worthwhile[4]. Of course, for Y_t^D, $Y_t^S \sim I(1)$, the existence of permanent shocks for both variables precludes bivariate cointegration between these and hence also precludes $\rho_{DS} = \pm 1$. Nevertheless, it does not preclude $\sigma_{DS} \neq 0$ in (15) for this case. Thus, conditional on a common information set I_t (which includes their lagged values), cross-economy innovations in Y_t^D and Y_t^S may be correlated. If these innovations relate to (say) technology or preferences, the existence of two distinct unit roots for these variables would premit changes in technology or preferences to be correlated across the economies, although perfect correlation would be ruled out. The dominance assumption for Y_t^D over Y_t^S then conditions on the former, and hence the permanent shock attributed to Y_t^S is purged of any (linear) commonality.

As indicated above, the dominance assumption enables the cross-economy system to be written in a conventional triangular form. However, the ordering of variables embodying dominance in order to ensure that B_0 is diagonal is not necessarily the same as the ordering of Y_t. In particular, different economies may be dominant for the distinct variables in the system, whereas Y_t would maintain a consistent ordering of economies (such as US, Euro Area) for all variables. Therefore, define an $[n+k] \times [n+k]$ matrix D that reorders the elements of Y_t as required such that B_0 in

$$B(L)\,D\Delta Y_t = \Pi\,DY_{t-1} + \varepsilon_t \tag{17}$$

is lower triangular. The analysis of the preceding subsection then applies in this reordered system, with dominance assumptions applying to elements of Y_{1t} or Y_{2t} of Y_t, associated with either permanent

[3] This result does not strictly apply in our SVAR specification, since additional restrictions are imposed compared to a general specification that includes lags of all variables and contemporaneous observations on variables prior to both Y_t^D and Y_t^S in the causal ordering.

[4] Note that this discussion excludes the case where one shock is permanent and the other transitory, which would be the case with Y_t^D, $Y_t^S \sim I(1)$ and cointegrated.

or transitory shocks, respectively.

3.2 SVECM Specification

Having considered the econometric issues, we now detail how these influence our SVECM specification.The observation vector for our system is defined as $Y_t = (y_t^{US}, y_t^{EA}, \pi_t^{US}, \pi_t^{EA}, r_t^{US}, r_t^{EA}, q_t)$, following the ordering used in Section 2 above, except that the unobserved output gaps are replaced by the corresponding (log) output series. In line with the existence of the long run equilibrium relationship in (4), our analysis is based on y_t^{US}, y_t^{EA}, $q_t \sim I(1)$. However, from an econometric perspective, (4) can be the unique long run relationship between these nonstationary variables only if they are cointegrated with $\beta' = (1, -\beta_1, 0, 0, 0, 0, -\beta_2)$ the single cointegrating relationship applying between the nonstationary elements of Y_t. Although the order of integration of inflation and nominal interest rates is sometimes debated, our specification assumes π_t^{US}, π_t^{EA}, r_t^{US}, $r_t^{EA} \sim I(0)$, in line with the vast majority of recent macroeconomic analyses undertaken in the context of a central bank with an active policy of managing inflation. Consequently, in terms of the discussion in subsection 3.1.1, we have $n = 3$ and $k = 4$, with a single cointegrating relationship applying for the former (hence $r = 1$). Therefore, the system contains $(n - r) = 2$ permanent shocks and $(k + r) = 5$ transitory ones.

The discussion of subsection 3.1.1 has three implications for the SVECM. Firstly, the variables that are the sources of the permanent shocks do not contain error correction terms. The two permanent shocks in our system are assumed to originate in the US and Euro Area output variables, y_t^{US} and y_t^{EA}, which is more palatable than considering real exchange rate shocks to be permanent; see also Dungey and Fry (2009) and Dungey and Pagan (2009). Although we do not identify these as necessarily being pure technology shocks, it is nevertheless worth noting that Uhlig (2009) recently finds differences in technological innovations to be the primary explanation for different monetary policy outcomes in the Euro Area and the US. Consequently, in our SVECM, the real exchange rate acts as a long run buffer to the effects of the distinct permanent shocks that impact on output in these economies. To maintain stationarity of all variables and to exclude an error correction term, the equations for y_t^{US} and y_t^{EA} must be written in terms of Δy_t^{US} and Δy_t^{EA}, rather than the output gap form used in (2) and (3).

The second implication of subsection 3.1.1 regards the representation of output gap effects in the remaining equations of the system. The representation (12) shows that these "gaps" depend on Δy_t and the disequilibrium from (4). Hence, analogously to Dungey and Pagan (2009) and also Dungey and Fry (2009), where $\widetilde{y}_t^{US}$ and $\widetilde{y}_t^{EA}$ enter the equations for π_t^{US}, π_t^{EA}, r_t^{US} or r_t^{EA}, their effects are captured by "correcting" Δy_t^{US} or Δy_t^{EA} (as appropriate) through the inclusion of the error correction term implied by (4).

Finally, stationary variables are written in the difference form of (6) by including levels effects through additional columns in a and β. With the definition $Y_t = (y_t^{US}, y_t^{EA}, \pi_t^{US}, \pi_t^{EA}, r_t^{US}, r_t^{EA}, q_t)$ and placing the adjustment coefficients to the single cointegrating relationship in the first column of α, all these implications are captured in the specification

$$\alpha = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \alpha_{31} & \alpha_{32} & 0 & 0 & 0 \\ \alpha_{41} & 0 & \alpha_{43} & 0 & 0 \\ \alpha_{51} & 0 & 0 & \alpha_{54} & 0 \\ \alpha_{61} & 0 & 0 & 0 & \alpha_{65} \\ \alpha_{71} & \alpha_{72} & \alpha_{73} & \alpha_{74} & \alpha_{75} \end{bmatrix} \begin{matrix} y_t^{US} \\ y_t^{EA} \\ \pi_t^{US} \\ \pi_t^{EA} \\ r_t^{US} \\ r_t^{EA} \\ q_t \end{matrix}. \tag{18}$$

To be specific, the assumption that the permanent shocks apply to y_t^{US} and y_t^{EA} implies $\alpha_{11} = \alpha_{21} = 0$ with $\alpha_{71} \neq 0$ being the adjustment of the real exchange rate to the disequilibrium. The remaining adjustment coefficients α_{i1} for $i = 3, 4, 5, 6$ arise from (12) by including long run adjustment terms to capture output gaps. The other four columns in (18) introduce the lagged levels terms for the stationary variables π_t^{US}, π_t^{EA}, r_t^{US}, r_t^{EA}. With β defined in a corresponding way to α, with the first column containing the coefficients of the cointegrating vector $(1, -\beta_1, 0, 0, 0, 0, -\beta_2)'$ and the remaining four columns having zeros as in (18) with unit elements replacing each α_{ij} (see also Dungey and Pagan, 2009). Note that these levels effects for the stationary variables are present whenever their differences enter a relationship, and hence the difference form for these in (6) is innocuous. With α and β defined in this way, the SVECM specification of (6) employs contemporaneous and lagged variables for B_0 and $B_L(L)$ as given for the short run economic model in (2) and (3).

It should be noted that the use of (2) defines the permanent shocks for y_t^{EA} as being conditional on those for y_t^{US}, which specifies US output shocks as being dominant for those of the Euro Area. As discussed in subsection 3.1.2, this involves conditioning Euro Area output shocks on those of the US. Hence, although Euro Area output shocks are permanent, the structure allows the evolution of US and Euro Area output series to be correlated in the short run with contemporaneous effects running from the US to the Euro Area.

Finally, it should be pointed out that the zero restrictions in $B(L)$ defined from (2) and (3), together with the error-correction mechanism, do not statistically ensure the mutual orthogonality of the shocks ε_t. This may or may not be an issue of practical importance, and will be assessed in the empirical application. The model is estimated using 3 lags in the levels of all variables, corresponding to two lags when expressed in changes. Optimal lag length choice is an area for future research.

4 Data

The Euro Area data for the empirical application are drawn mainly from the updated Area Wide Model (AWM) database (originally developed within the European Central Bank by Fagan, Henry and Mestre, 2005), together with extensions to that database discussed in Anderson, Dungey, Osborn and Vahid (2008). The US data are drawn directly from the FRED database, made available by the Federal Reserve Bank of St Louis.

Euro Area GDP is from the AWM database of November 2008. However, the construction of monetary series in the AWM database using fixed historical (GDP) weights is not not attractive, as it tends to overweight the contributions of countries such as Italy and Portugal for periods when these countries did not follow disciplined monetary policy as (for example) in Germany. Therefore, we adopt the historical inflation and interest rate data calculated by Anderson et al. (2008) using a sliding weight mechanism developed in order to represent the progress towards monetary union. However, from February 1994 Euro Area HICP inflation data are used, while the interest rate is represented by the 3 month Euribor rate from the beginning of 1992. Inflation is measured at an annual rate throughout, with an adjustment to account for German reunification. The approach and sliding weights of Anderson et al. (2008) are used to construct a bilateral nominal exchange rate series (US dollars per euro) for the period prior to the introduction of the euro in January 1999. The real exchange rate is then constructed using this and price indices constructed from the US and Euro Area inflation rates. Further details are included in the Appendix, which also includes graphs of the series.

The data are quarterly, and the period considered in this paper is 1983Q1 to 2007Q4. This represents the period of the move towards a common currency in Europe, which is frequently dated from the establishment of the European Monetary System in March 1979, since this involved an exchange rate mechanism linking the currencies of the participating countries. From the US perspective, the sample begins after the Volker experiment period of the early 1980s, and corresponds to a period when inflation can be modelled as a stationary series (Halunga, Osborn and Sensier, 2009).

Before turning to the results, it is useful to comment on the extent of international interactions. The (simple) correlation between the growth rates of output in the two economies is moderate at 0.16, but the cross-economy inflation rates and short run interest rates are much more highly correlated at 0.46 and 0.61, respectively. While the latter may be a consequence of similar monetary policies operated across these economies, the inflation correlation is strong, in line with recent analyses of the globalization of inflation (for example, Borio and Filardo, 2007, Ciccarelli and Mojon, 2009).

5 Results

The first step in the estimation of the SVECM model for the Euro Area and the US is to establish the existence of cointegration between US and Euro Area output and the real exchange rate (all in logarithmic form). Cointegration between the two output series alone is not supported, but a single cointegrating vector is indicated for these two variables with the real exchange rate[5]. This suggests that (4) is, indeed, a meanginful long run relationship. When estimated as the first step of an Engle-Granger procedure, this yields

$$y_t^{EA} = 0.7323 y_t^{US} + 0.0362 q_t + 7.3708 + ecm_t \tag{19}$$

where ecm_t is the estimated disequilibrium at time t. Note that (19) implies differential trend rates of output growth in the two economies, as also indicated by the data characteristics; see the figure plotted in the Appendix.

5.1 International Inflation Linkages

As noted in Section 3, our SVECM specification does not guarantee the orthogonality of the shocks in the system, although such orthogonality is assumed for conventional impulse response analysis. The correlations of the residuals for the estimated system given by (2) and (3), in conjunction with error-correction terms of (18), in the SVECM system (6) are shown in Table 1. While it is evident from Table 1 that most of the residual series are approximately orthogonal, it is also clear that the New Keynesian specification as implemented here is unable to explain the strong positive contemporaneous correlation between inflation in the two economies, 0.655 in the Table. Although one potential explanation is the omission of a variable representing common international inflationary shocks, such as the commodity price inflation suggested by Sims (1992), in our case the addition of exogenous commodity price

[5] Allowing linear trends in the data, but no trends in the cointegrating relation(s), both the trace and maximal eigenvalue statistics suggest the presence of cointegration, with p-values below 0.02. However, the p-value for a second cointegrating vector is 0.25 or 0.28, respectively, for the two tests. These preliminary results were obtained using EViews with augmentation by 3 lags, as required to eliminate serial correlation. We also undertook cointegration analysis conditioning on the remaining (stationary) variables of the system, namely π_t^{US}, π_t^{EA}, r_t^{US}, r_t^{EA}. However, presumably due to our relatively short sample and the persistence exhibited by these stationary variables, the results did not imply a plausible cointegrating relationship between y_t^{US}, y_t^{EA} and q_t.

Table 1: Residual correlations

	y_t^{US}	y_t^{EA}	π_t^{US}	π_t^{EA}	r_t^{US}	r_t^{EA}	q_t
y_t^{US}	1.00						
y_t^{EA}	.005	1.00					
π_t^{US}	.007	.136	1.00				
π_t^{EA}	.006	.025	.655	1.00			
r_t^{US}	.025	-.016	.002	.093	1.00		
r_t^{EA}	.105	-.005	-.029	-.001	.054	1.00	
q_t	-.029	-.032	-.027	-.012	.035	.025	1.00

inflation to the system does not serve to reduce this problem[6].

The implication of this result is that inclusion of the foreign output gap in the Phillips curve is unable to capture the commonality of US and Euro Area inflation experiences over our sample period. This is consistent with the finding of Dees, Pesaran, Smith and Smith (2009) that foreign variables provide important information for the Phillips curve. In our case, the SVECM specification may not take sufficient account of inflation expectations, specifically the possibility that inflation expectations in one economy are influenced by inflation experiences in the other. To allow for such an effect, the open economy results presented below include direct inflation linkages in our extended specification. To be specific, we impose the assumption of US dominance for inflation, in addition to that for output, by removing the zero restrictions on the coefficient b_{43}^0 in (2), and on cross-economy feedback effects through lag polynomial coefficients b_{43}^L and b_{34}^L in (3). US dominance is supported by the results in Galesi and Lombardi (2009), although the differences they report are not overly large. One implication of the US dominance assumption for (contemporaneous) inflation is that Euro Area monetary policy responds within the current period to a US inflation shock, due to the latter's impact on Euro Area inflation. This is more plausible that an assumption of Euro Area dominance for inflation.

Allowing these inflation linkages, the correlation matrix of the SVECM residuals becomes that of Table 2. which has orthogonal cross-economy inflation shocks. As can be seen from this table, the remaining residual correlations are relatively small, with values of 0.12 or less. Nevertheless, it may be noted that the positive cross-economy correlations of around 0.1 remain between the pairs (π_t^{US}, y_t^{EA}), (r_t^{US}, π_t^{EA}) and (y_t^{US}, r_t^{EA}).

[6] In any case, given the importance of the two economies for the world economic system, such an assumption of strict exogeneity for commodity prices is not attractive.

Table 2: Residual correlations with inflation interactiions

	y_t^{US}	y_t^{EA}	π_t^{US}	π_t^{EA}	r_t^{US}	r_t^{EA}	q_t
y_t^{US}	1.00						
y_t^{EA}	.005	1.00					
π_t^{US}	.008	.121	1.00				
π_t^{EA}	-.001	.026	.000	1.00			
r_t^{US}	.025	-.016	.012	.116	1.00		
r_t^{EA}	.102	-.004	-.023	.005	.057	1.00	
q_t	-.029	-.032	-.035	.029	.035	.030	1.00

Table 3: Sizes of one-standard deviation shocks to the model

Variable	Size	Variable	Size
y_t^{US}	0.46%	y_t^{EA}	0.43%
π_t^{US}	1.95% p.a.	π_t^{EA}	0.87% p.a
r_t^{US}	33 basis pts	r_t^{EA}	30 basis pts
		q_t	3.71%

Despite the relatively high correlation between the interest rate series for the two economies, as noted in Section 4, the domestic monetary policy reaction functions do a good job of taking account of this, as evidenced by the small residual correlation between r_t^{US} and r_t^{EA} in Table 1.

5.2 Impulse Response Analyses

We now turn to the impulse responses implied by our empirical two-economy SVECM specification, with responses to domestic shocks discussed first and cross-economy responses in subsection 5.2.2. All shocks are set equal to one standard error for the model extended to capture inflation linkages, with these standard errors presented in Table 3. The smaller magnitude of Euro Area inflation shocks is due to the assumption of US inflation dominance, and hence the conditioning of these shocks on US inflation, as in (16)[7]. The impulse response results presented below include bootstrapped one standard deviation error bands for the two-economy model, which are estimated using 10000 random draws (with replacement) from the SVECM residuals[8].

[7] We thank David Fielding for discussions on this point.

[8] To be precise, the bands represent one standard deviation if the residuals are normally distributed, and cover 67.3% of the bootstrapped responses.

5.2.1 Domestic Responses

The responses in our SVECM specification to shocks that originate within one economy are influenced by the short run and long run interactions that are permitted between the US and the Euro Area. In order to provide information on the role of these interactions, separate closed economy SVAR models are also estimated for comparison purposes. The closed economy specification in each case contains four variables, namely domestic output, inflation and interest rates, together with the (bilateral) real exchange rate. The model is a standard VAR, with the triangular contemporaneous structure of (2) and feedbacks as in (3). However, as closed economy models, foreign output is excluded from the domestic output equation, foreign inflation is excluded from the Phillips curve relation and no foreign variables enter the Δq_t equation.

The closed economy set-up precludes using cointegration between domestic and foreign output levels and the real exchange rate. Therefore, the $I(1)$ nature of the output and exchange rate data is accounted for by first differencing these variables. Thus the estimated system in each case is an SVAR in Δy_t^i, π_t^i, r_t^i ($i = US$ or EA) and Δq_t, with the real exchange rate responding to all variables in the (closed economy) model; a lag order of 2 is employed in each case, as for the two-economy SVECM specification. Variables are defined in the same way for each country, with an increase in the exchange rate representing an appreciation of the Euro relative to the US dollar. To facilitate comparison, the magnitude of shocks applied in each closed economy specification is as given in Table 3.

Figure 1 shows the results for the key monetary policy effects of inflation shocks on interest rates and vice versa, with results for the US in the left-hand panel and the Euro Area in the right-hand one. A number of features are evident. First, the closed economy responses (in red) are generally lie outside the open economy error bands, with the single exception of the US inflation response to a monetary policy shock. Secondly, the open economy responses are subsantially more in line with theory, with this especially clear for the Euro Area. More specifically, in panel (c), an inflation shock causes a strong monetary response, with Euro Area interest rates increasing significantly (in terms of the error bands) when the open economy SVECM is employed, whereas an implausible negative response is implied in the closed economy case. Further, panel (d) reveals that the closed economy SVAR suffers from the price puzzle, whereas inflation falls in response to an interest rate increase in the Euro Area when the open economy model is employed. Van Aarle, Garretson and Gobbin (2003) also find price puzzles when comparing closed economy SVAR models of the US and Euro Area.

For the US economy, both specifications show some evidence of a price puzzle in panel (b), although this is more muted in the open economy specification[9]. However, more substantial differences are revealed in panel (a) when the open economy SVECM is compared with the closed economy SVAR. In the latter case, the monetary response to inflation is much more muted, and in relation to the closed economy error bands (not shown) insignificant. However, when feedback effects from the Euro Area are taken into account, a strong monetary response applies.

Thus, domestic responses to domestically-sourced shocks are affected when international interactions are taken into account, with this being the case even for the dominant US economy. The next subsection therefore examines the cross-economy responses to shocks emanating from each of these regions.

5.2.2 Cross-Economy Responses

Figure 2 illustrates the nature and importance of the international relationships, by showing the estimated impulse responses of output, inflation and interest rates in the Euro Area to shocks originating in the US. A (permanent) shock to US output leads to an increase in Euro Area output, Figure 2(a), albeit small and insignificant. Euro Area inflation shows a small increase for some 5 years after the shock and there are small initial rises in the Euro Area interest rate, reflecting that the source of the shock is international, Figure 2(b and c). In constrast, US inflation shocks have substantial and significant impacts on Euro Area inflation and interest rates, with the US shock of around 0.5% leading to increases of about 0.2% in both Euro Area variables. This effect is immediate for inflation, but has a substantial delay for interest rates. US monetary policy shocks cause a marginally significant rise in Euro Area output, due to the associated deprecation of the euro and consequent rise in Euro Area inflation, Figures 2(g and h). Thus, the US output shock ultimately causes a monetary policy response in the form of higher Euro Area interest rates, Figure 2(i).

US variable responses to Euro Area shocks, shown in Figure 3, are typically less strong than those of Figure 2, as may be anticipated from the world role of the US and the dominance assumptions we make for US output and inflation. Nevertheless, and as implied by the results discussed in subsection 5.2.1, the US responses are significant in a number of cases.

Despite Euro Area output shocks having largely insignificant impacts on US output or inflation, Figure 3(a and b), their effects are sufficient to result in a significant fall in US interest rates, Figure 3(c). Indeed, the interest rate response is quicker and of similar magnitude to that of the Euro Area in Figure 2(c) (recall from Table 3 that the output shocks are similar in these two cases). Another

[9] Indeed, this price puzzle effect is removed if foreign output is dropped from the Phillips curve.

aspect of interest is the asymmetric responses of the different countries to inflation shocks sourced internationally. While higher US inflation lead to a temporary increase in Euro Area output, Figure 2(d) higher Euro Area inflation has the opposite effect on US output, Figure 3(d). Nevertheless, and despite the contemporaneous dominance assumed for US inflation, the US experiences significant spillovers from Euro Area inflation, Figure 3(e). Further, an increase in Euro Area interest rates results in a fall in US output, Figure 3(g), which can be rationalized as the associated depreciation of the US dollar not being sufficient to stimulate net exports to the Euro Area and hence not overcoming the reduced demand from the Euro Area due to its tighter monetary policy; contrast Figure 2(g to i) with 3(g to i), and see also Figure 4(a and b).

The impulse responses of the real exchange rate to each of the shocks in the system are as expected, Figure 4(a and b) give the effects of interest rate shocks from each region on the exchange rate. Of more interest are the reactions of the variables in the system to real exchange rate shocks. Exchange rate shocks are notoriously difficult to interpret, however, in this case there are a few effects worth considering. An unexpected real depreciation of the US dollar (increase in the real exchange rate) has a negative effect on US output, Figure 4(c), and a similar effect on Euro Area output, Figure 4(f). Although one would expect that output effects should be opposite as one country experiences a deprecation of its currency and the other an appreciation, clearly the feed-through of the US output effects to the Euro Area are dominant - the strength of these effects are shown in Figure 2(a). The inflationary effects of exchange rate shocks are large and significant for the Euro Area, Figure 4(g), but not for the US, Figure 4(d). The relative sizes of the effects is consistent with research showing that the a US Taylor rule should not include an exchange rate effect (for the mixed evidence on other countries see Lubik and Schorfheide, 2007). The consequence of these effects is that the exchange rate shock has a significant effect on the interest rate in the Euro Area, but not the US, with the lower output and inflation in the Euro Area shown in Figure 4(f and g) being consistent with the lower Euro Area interest rates shown in Figure 4(h). Finally, it may be noted that although the exchange rate shock is transitory, it is nevertheless long-lasting (Figure 4(i)).

It is clear from these results that our open economy model, which allows the effects of shocks to flow in both directions between these economies, reveals empirically the richness and complexity of underlying economic relationships. Overall, the strongest international effects flow through inflation and interest rates, although foreign output shocks also play a role for the latter.

6 Conclusions

The contribution of this paper is to provide an empirical model of the interactions between two large economies, the Euro Area and the US, both of which are modelled as open but where the US is dominant in terms of the direction of contemporaneous influence. One conduit for achieving openness is the recognition of reversion towards the long run equilibrium output relationship present in the theoretical New Keynesian models, such as Clarida, Gali and Gertler (2002), Gali and Monacelli (2005) or Monacelli (2005). Implementation of both short and long run restrictions, using the methods of Pagan and Pesaran (2009), enable the empirical model to represent the key features of the New Keynesian theoretical framework. Additionally, the approach has the advantage of distinguishing permanent and transitory shocks in a single empirical SVECM specification.

One important finding of the paper is that an identification scheme motivated by modern New Keynesian theory leaves uncaptured common inflationary correlations between the two regions. By allowing for direct interactions between the inflation rates, an empirically more acceptable specification is obtained. Consequently, theoretical models may need to consider how foreign inflationary shocks can be more directly incorporated into the price formation of the domestic economy. Further, recent empirical analyzes of the impact of globalization on domestic (often US) inflation may need to be reconsidered, since many of these (including Borio and Filardo, 2007, Ihrig *et al.*, 2007, Milani, 2009) capture globalization primarily through the inclusion of a foreign output in the Phillips curve. In our two-economy setting, this does not provide a satisfactory representation of the empirical links for inflation.

Another general finding is that, even when the US economy is treated as dominant over the Euro Area for contemporaneous output and inflation linkages, the Euro Area nevertheless has important feedback effects on the US, with these evident even when examining responses to domestic US shocks. This finding, along with the sometimes substantial effects of shocks emanating in the Euro Area on US variables, indicate that the US economy is not adequately modelled as one closed to international influences. Of course, this last statement applies with at least equal force to the Euro Area.

Two immediate important extensions are apparent to this work. The first is to expand the model to include the capacity for further financial sector transmission mechanisms across countries, these may occur through international equity markets, as in Dees, Pesaran, Smith and Smith (2009), and long dated bond markets. Additionally, the current model incorporates only two large economies, the inclusion of further small open economies as part of an extended system is a future research agenda.

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7 Appendix: Details of Data Series

US GDP: Quarterly Real US GDP, from FRED database, series identifier GDPC96

US Inflation: Consumer price index, all items, quarterly averages of monthly inflation calculated from FRED database, series identifier CPIAUCSL.

US interest rate: 3 month Treasury bill rate, quarterly average of monthly series, from Fred database, series identifier TB3MS

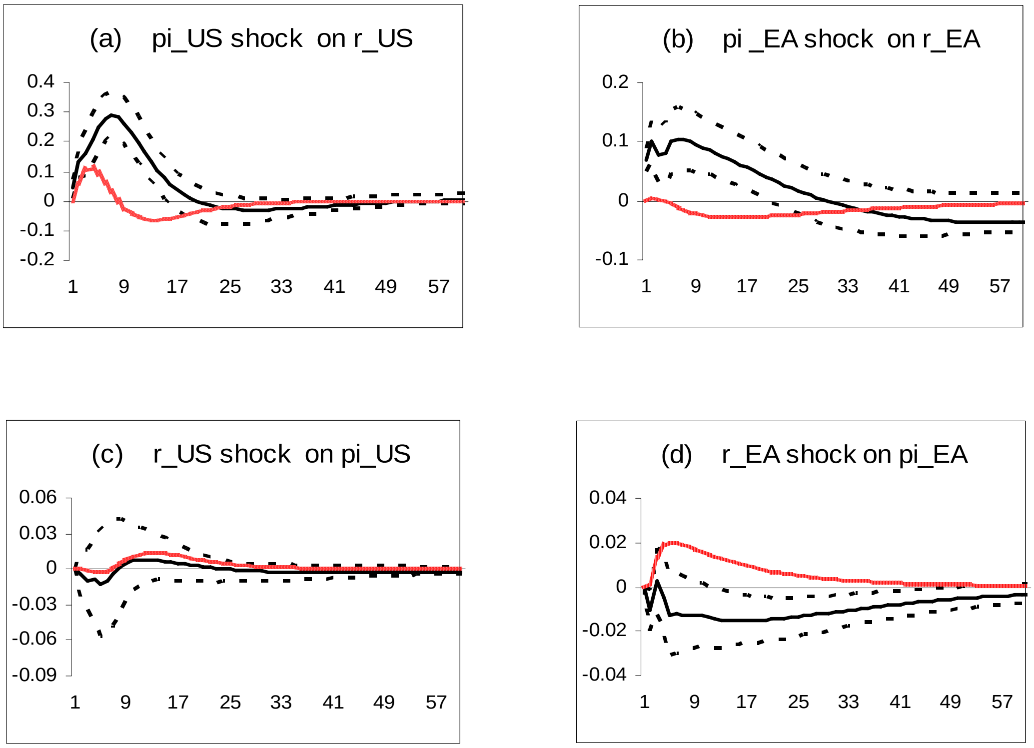
Euro Area GDP: Quarterly Real GDP for the Euro Area from the Area Wide Model database (available on http://www.eabcn.org), series identifier YER.

Euro Area Inflation: Sliding weight constructed Euro Area individual country inflation data as per methodology of Anderson *et al* (2008) for the period until February 1994, when the series is spliced to the HICP series available from Eurostat, the reunification of Germany is handled by redistributing the quarterly changes across the changes in inflation controlling for the short lived levels effect.

Euro Area Interest rate: 3 month rate constructed from Euro Area individual country interest rate data as per methodology of Anderson *et al* (2008) for the period prior to 1992, when the series is spliced to the 3 month Euribor.

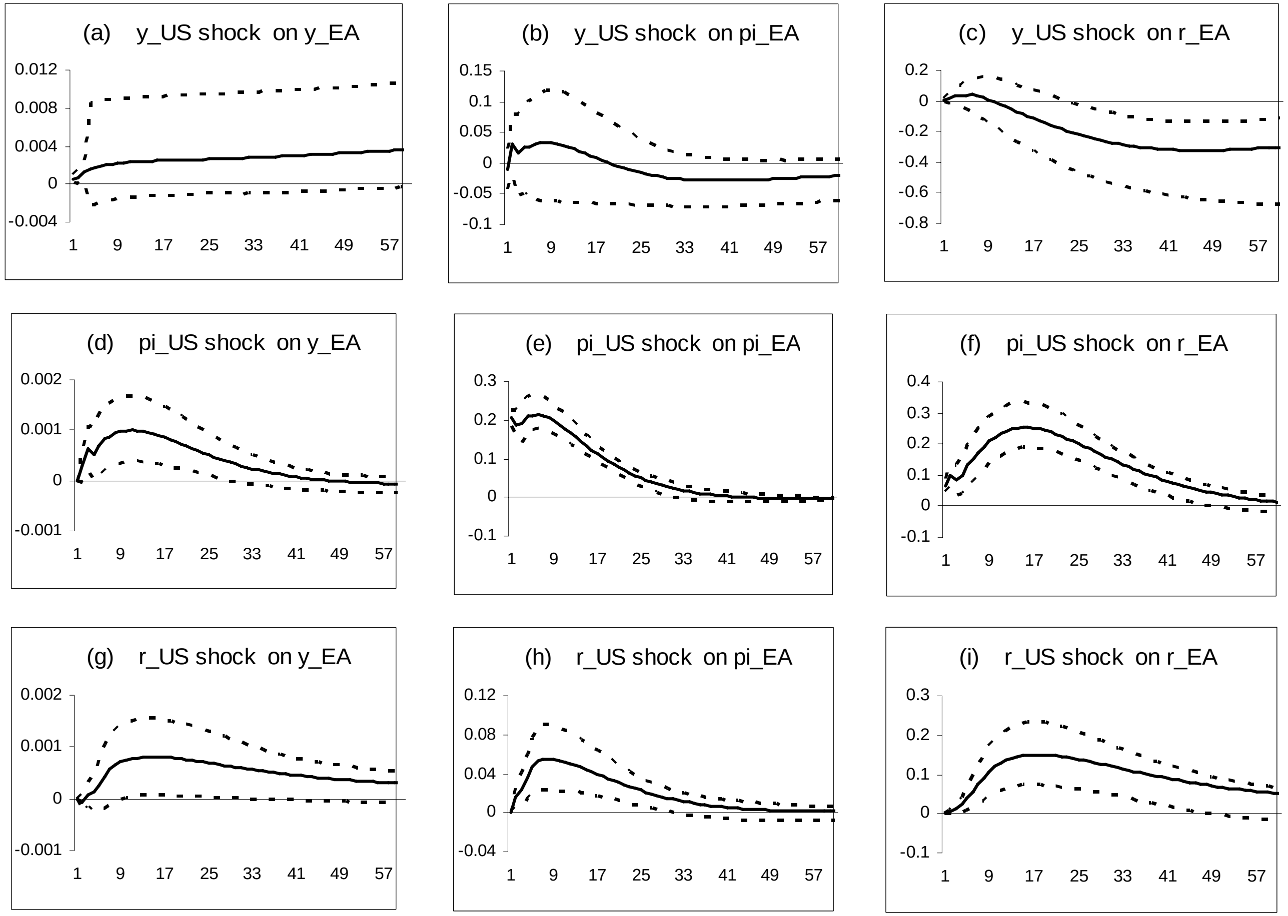
Exchange rate: Euro/USD exchange rate constructed from Euro Area individual country exchange rates against the US dollar as per methodology of Anderson *et al* (2008) for the period prior to 1999, then follows the ECB reference rate from the beginning of 1999.

Figure 1. US and Euro Area Impulse Responses to Own Inflation and Monetary Policy Shocks



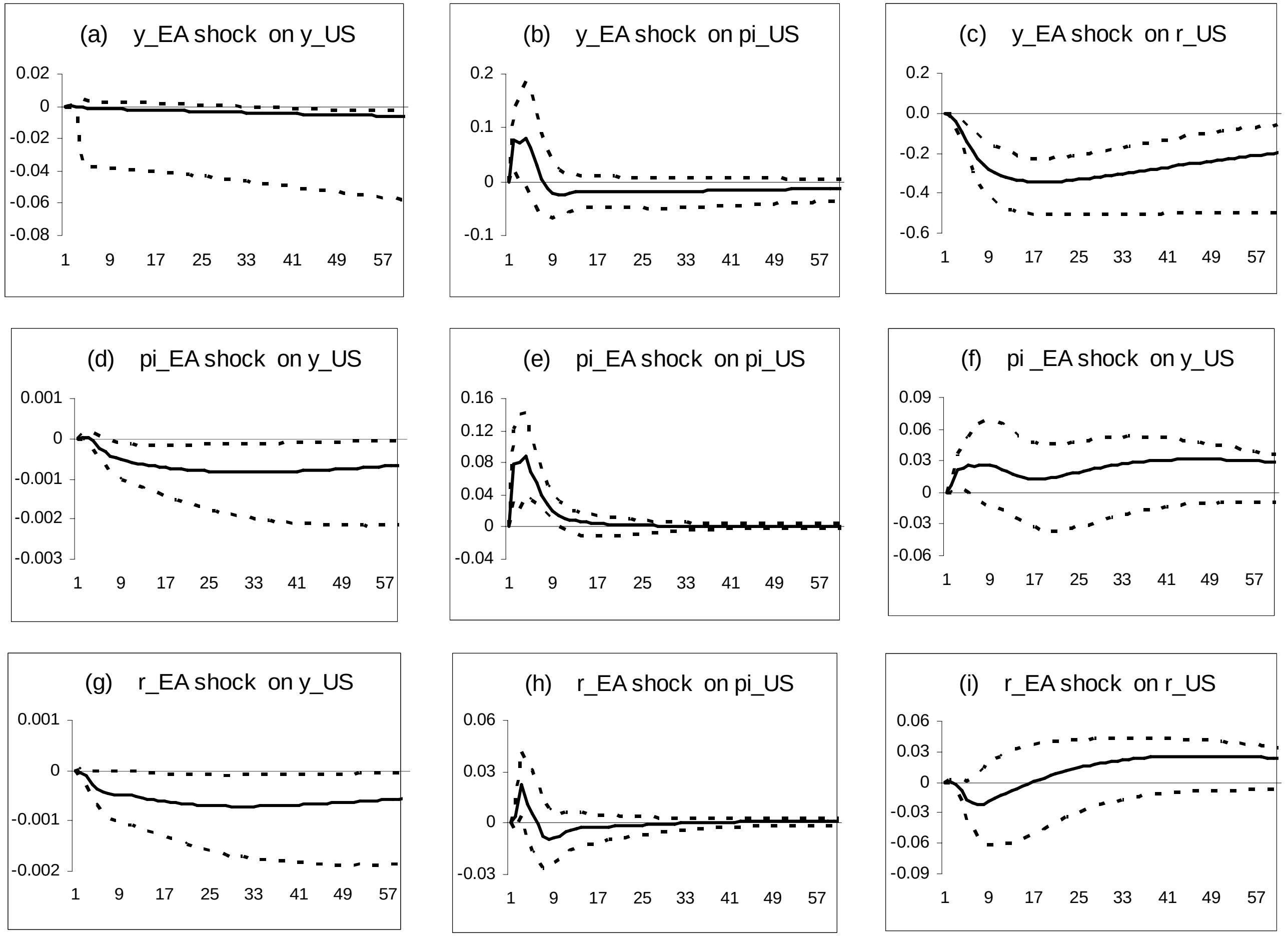
Notes: Impulse responses to own economy shocks in the SVECM for the US and Euro Area are shown as unbroken black lines, with their one standard error bands (obtained from 5000 bootstrap replications) indicated by dashed black lines. The patterned red line indicates responses to a shock of the same magnitude applied in the closed economy SVAR model.

Figure 2. Impulse Responses of Euro Area Variables to US Shocks



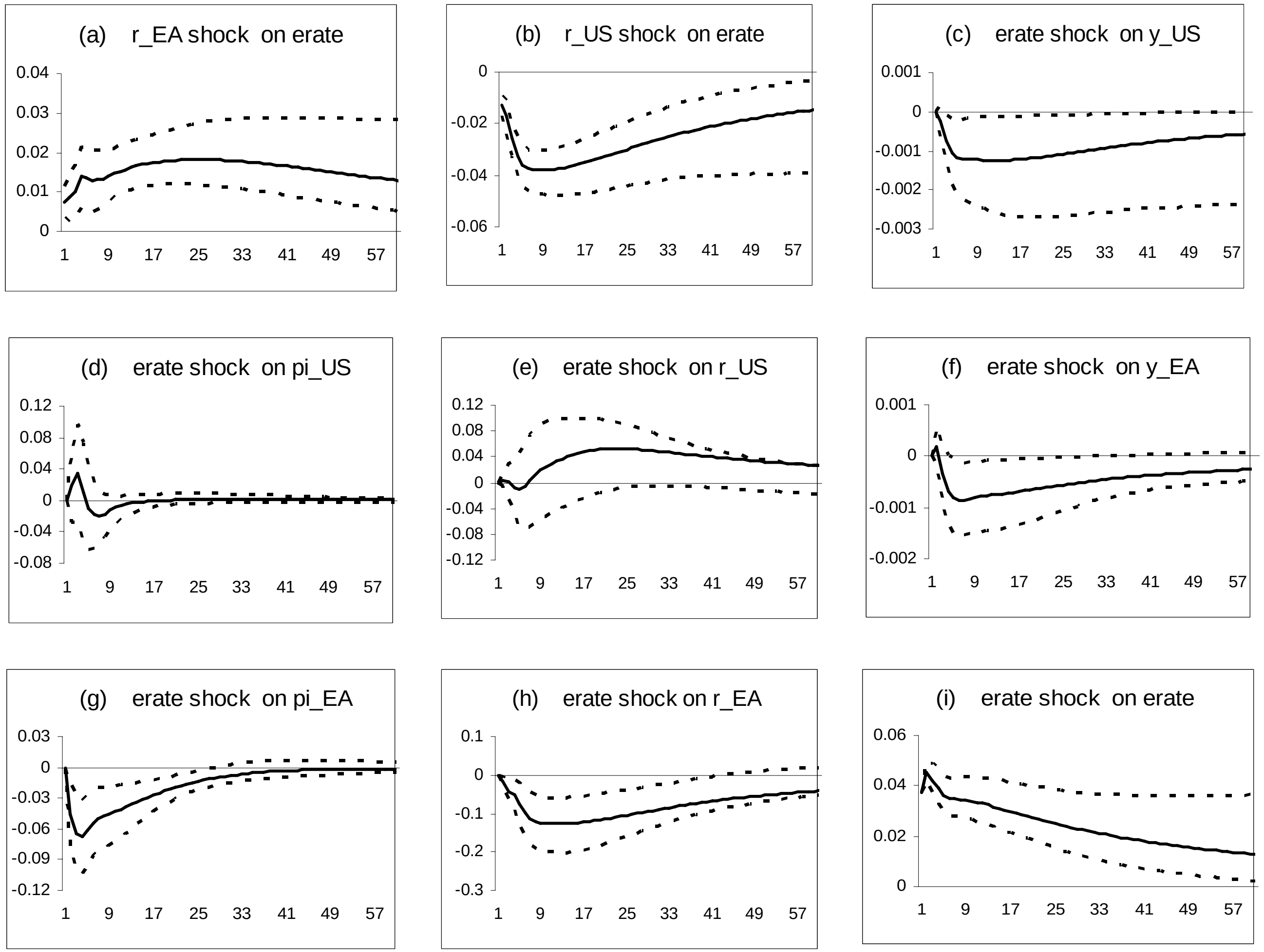
Notes: Impulse responses are shown as unbroken black lines, with their one standard error bands (obtained from 5000 bootstrap replications) indicated by dashed black lines.

Figure 3. Impulse Responses of US Variables to Euro Area Shocks



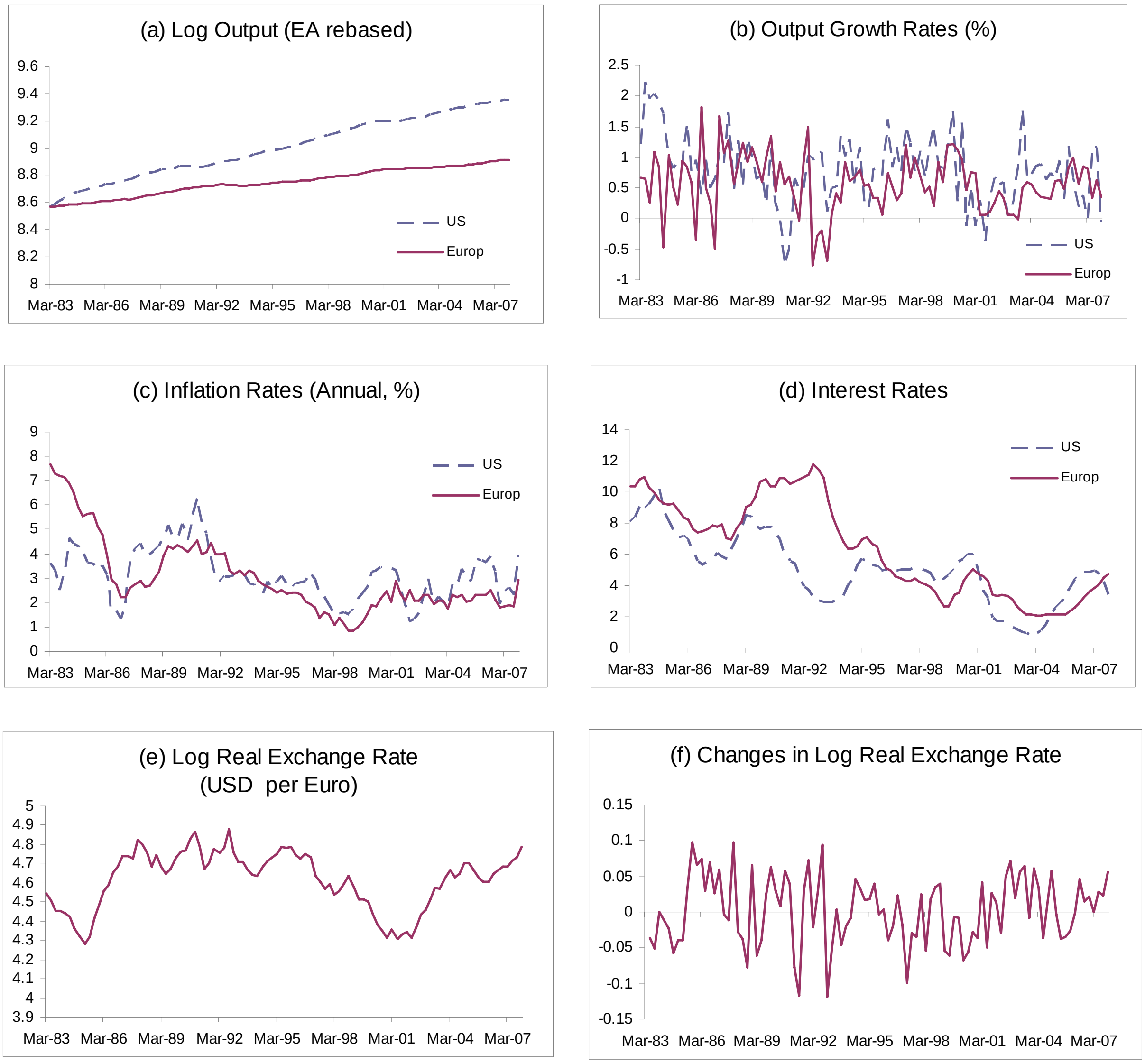
Notes: See Figure 2.

Figure 4. Exchange Rate Impulse Responses



Notes: See Figure 2.

Appendix Figure. Data Graphs



Notes: Euro Area GDP in panel (a) is rescaled to be equal to that of the US in 1983Q1.