

# International Linkages for Large Open Economies with a SVAR Representation\*

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## Abstract

International linkages between the Euro Area and the US are investigated through a structural VECM which imposes long run and short run cross-economy restrictions. Importantly, greater empirical coherence is obtained by allowing for more direct inflationary effects between the two economies than is traditional. Our SVECM distinguishes between permanent and temporary shocks, with the former attributed to distinct technology shocks in the two economies. The model is estimated using data over 1983Q1 to 2007Q4 and demonstrates the impact of shocks in each country on the other, although those in the US produce stronger effects.

**Keywords:** New Keynesian Open Economy Model, SVAR, Euro Area

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# 1 Introduction

One of the most interesting and challenging issues in modelling open economies is how to accommodate the interactions between economic regions in an empirically and theoretically sensible way. A common response has been to adopt a small open economy structure, so that the larger (implicitly closed) economy does not receive any shocks or feedback from the smaller open economy, see for example the early structural VAR work of Cushman and Zha (1997), structural models such as the GTAP world trade model, and recent developments in a New Keynesian framework initiated by Gali and Monacelli (2005). However, this does not represent the reality of interactions between major economic players, such as the US and Euro Area. Although the general empirical finding to date is that the US is relatively less affected by world conditions than the Euro Area, nevertheless there is a growing recognition that world conditions play an important role for even the US economy; see, for example, Ciccarelli and Mojon (2009), Kose, Otrok and Whiteman (2008) or Perez, Osborn and Artis (2006)<sup>1</sup>.

New Keynesian models provide an attractive theoretical framework for empirical analyses conducted using structural Vector Autoregression (SVAR) specifications. However, these models also have some limitations when applied in an international context. In particular, empirical applications generally find that estimates of individual country parameters are incredibly similar despite the data having different characteristics and the countries operating in different institutional settings. Thus, for example, the parameter estimates for Europe and the US obtained by Smets and Wouters (2005) and Lubik and Schorfheide (2005) are very alike. Further, and more importantly, using Canadian and US data, Justiniano and Preston (2006) show that the modelling structure fails to replicate a number of important characteristics of the data, in particular the observed correlation between output in the two countries.

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<sup>1</sup>Recent work by Dees, di Mauro, Pesaran and Smith (2007) has extended the analysis of empirical interactions between economies using the global VAR (GVAR) framework, while intertemporal general equilibrium models such as G-cubed described in McKibbin and Wilcoxon (1995) have also been developed.

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 empirical restrictions applied are based on interdependent economies in an open economy modelling setting, where one economy (the US) is dominant in terms of the sources of real shocks, but there are also dynamic transmissions 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. Since 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 interpretable 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, as usually associated with a standard SVAR, with these interpreted in our context as international business cycle interactions. The long run relationship between output in the two countries gives rise to an additional feedback mechanism via the error correction parameters. Thus the open economy relationships between the Euro Area to 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 throughout this period through the development and operation of the European Monetary System, while US monetary policy has been relatively stable. The key results 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 negligible.

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 empirical 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 presents some benchmark results from closed economy SVAR models, while Section 6 contains our substantive empirical results. Finally, Section 7 concludes.

## 2 Framework

Most recent theoretical and empirical advances in modelling international interactions have occurred in the small open economy framework, with important advances in the New Keynesian framework associated with Woodford (2003) extended to open economies by Gali and Monacelli (2005), Monacelli (2005), Lubik and Schorfheide (2007), Gertler, Gilchrist and Natalucci (2007) and Justiniano and Preston (2008). However, empirical implementations of open economy New Keynesian models, such as in Lubik and Schorfheide (2005), Justiniano and Preston (2008) and Buncic and Melecky (2008), reveal estimates of key parameters that are often surprisingly similar across the different economies. A developing literature discusses econometric issues associated with these models, including Justiniano and Preston (2008), Kapetanios, Pagan and Scott (2006) and Fukac and Pagan (2008), with one focus being the potential role of priors employed in the Bayesian approach to estimation commonly used to deliver identification of the parameters of interest (Lubik and Schorfheide, 2005).

The extent to which the US and Euro Area economies are similar is an open issue. In a comparison of the two economies in a closed economy DSGE setting, Smets and Wouters (2005) find them to be very similar overall, although the Euro Area does show lower degree of habit persistence and greater price

stickiness. Nevertheless, they acknowledge the possible limitation imposed by their use of a common structure, including common priors, for both. On the other hand, in a SVAR framework, van Aarle, Garretson and Gobbin (2003) find that demand shocks are associated with larger and longer effects in the Euro Area than the US.

Estimation of a DSGE model can be difficult and these models do not always capture the empirical characteristics of the data. However, Smets and Wouters (2003) demonstrate that these models can deliver empirical specifications that compare well with those arising from a conventional VAR approach. Further, Del Negro and Schorfheide (2003) embed the DSGE in a VAR by progressively relaxing the cross-equation restrictions of the latter, and show that the so-called DSGE-VAR improves the empirical fit of the model while making little difference to its qualitative implications. Del Negro, Schorfheide, Smets and Wouters (2007) develop the DSGE-VAR approach further to evaluate model misspecification and to assess forecasting performance.

VAR representations of DSGE models are generally of relatively low order, given the limited dynamics in the theoretical DSGEs. However, the dynamics present in the data can be substantially greater. A number of authors have addressed the difficulties incumbent as a result of this including Del Negro, Schorfheide, Smets and Wouters (2007), Christiano, Eichenbaum and Vigfusson (2006), Chari, Kehoe and McGrattan (2007), Fry and Pagan (2005) and, originally, Zellner and Palm (1974) and Wallis (1977).

As pointed out by Del Negro and Schorfheide (2003), the DSGE-VAR approach is particularly relevant for representing the impact of exogenous shocks, which are often incorporated as ad hoc dynamic mechanisms. Such exogenous shocks are often technological and, with an assumption of common world technology, this provides one possible way of accommodating open economy influences that is nevertheless compatible with the essential features of a DSGE specification. However, instead of starting from a severely restricted DSGE version of a VAR and successively relaxing restrictions, here we take adopt the theoretical structure suggested by these models to specify a relatively lightly

restricted SVECM. This has the advantage of capturing empirical relationships while building on the theoretical framework, but also incorporates permanent relationships between series in order to distinguish permanent and temporary shocks, as in Pagan and Pesaran (2009), Dungey and Pagan (2009) and Dungey and Fry (2008). Thus, cointegrating relationships relate to technology effects and connect long run output movements in the US and the Euro Area. The spillovers between these economies are accommodated via the error correction terms in a way which allows us to relax, at least partially, the small open economy assumption.

To motivate the identification structure of our interdependent economy model, we recognise that each individual economy can be represented as possessing an open economy IS curve, which reveals the effects of output, real interest rates, the exchange rate and output in the foreign economy on domestic output. A specification of this form can be obtained from micro foundations using a framework such as that of Gali and Monacelli (2005) where the exchange rate and foreign output effects enter via incomplete pass through introduced in Monacelli (2005). Each economy also possesses an open economy Phillips curve, where inflation depends on past inflation, an output gap and exchange rate changes, where the latter term again can be theoretically justified by the incomplete pass through model of Monacelli (2005).

The monetary policy response function is given by the standard interest rate rule which involves interest rate smoothing as well as a central bank loss function focussed on output gap and inflation with a potential allowance for response to foreign price effects via the exchange rate. In practice a great deal of evidence supports the effects of the exchange rate to be negligible, for example Lubik and Schorfheide (2007), which is consistent with claims by central banks that they respond to domestic economic conditions alone.

Thus, a baseline open economy New Keynesian model for each domestic

economy (the US or Euro Area) can be written as

$$\begin{aligned}\tilde{y}_t = & \beta_0 + \beta_1(L)\tilde{y}_t^* + \beta_2(L)\tilde{y}_{t-1} + \beta_3(L)\pi_{t-1} + \beta_4(L)r_{t-1} \\ & + \beta_5(L)\Delta q_{t-1} + \varepsilon_{t,y}\end{aligned}\quad (1)$$

$$\pi_t = \gamma_0 + \gamma_1(L)\tilde{y}_t + \gamma_2(L)\pi_{t-1} + \gamma_3(L)\Delta q_{t-1} + \varepsilon_{t,\pi}\quad (2)$$

$$r_t = \delta_0 + \delta_1(L)\tilde{y}_t + \delta_2(L)\pi_t + \delta_3(L)r_{t-1} + \varepsilon_{t,r}\quad (3)$$

where  $\tilde{y}_t$ ,  $\pi_t$ ,  $r_t$  and  $q_t$  represent the domestic output gap, inflation, the short run interest rate and the real exchange rate, respectively, while \* indicates the other economy and  $L$  is the conventional lag operator. Within each economy, the usual contemporaneous causal ordering is imposed in (1) to (3). Although the form of the equations is otherwise identical for the two economies, the coefficient  $\beta_1(0)$  on  $\tilde{y}_t^*$  (that is, the coefficient on the contemporaneous Euro Area output gap) is set to zero in (1) for the US specification, reflecting the dominant role of the US economy for international business cycle movements. The bilateral (log) real exchange rate,  $q_t$ , is treated as a nonstationary  $I(1)$  variable. A final equation is required to close the model, which is usually provided by a UIP condition in the standard open economy New Keynesian framework.

### 3 Econometric Specification

Our empirical specification builds on (1) to (3) in a number of ways. Firstly, we recognise that a long-run relationship should be anticipated between output in the US and Euro Area, implying the existence of a cointegrating relationship involving the output variables  $y_t$  and  $y_t^*$ . Secondly, this long-run relationship itself has implications for the nature and modelling of the output gap measures  $\tilde{y}_t$  and  $\tilde{y}_t^*$ . Finally, we relax the UIP restrictions and employ a more general specification for the real exchange rate.

The issues associated with forming an estimable econometric specification are discussed in the present section, beginning with the implications of the presence of long run relationship(s) for the specification outlined in (1) to (3).

### 3.1 Permanent and Transitory Shocks

The generic representation of our empirical SVAR model can be written as

$$G(L)Y_t = \varepsilon_t \quad (4)$$

where  $Y_t$  is the matrix of  $T \times (n + k)$  endogenous variables in the system and  $G(L) = G_0 - G_1L - G_2L^2 \dots$ . However, the nonstationary  $I(1)$  nature of the output (and possibly other) variables in our system needs to be recognised. In many New Keynesian applications, such as Lubik and Schorfheide (2007) for example, this is taken into account by examining an output gap form and assuming all other variables are  $I(0)$ . However 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. Therefore, this paper takes advantage of the  $I(1)$  nature of these variables by exploiting cointegration to provide identification restrictions.

To provide a general discussion, assume that  $n$  variables in  $Y_t$  are  $I(1)$  and the remaining  $k$  variables are  $I(0)$ . If  $r$  cointegrating relationships exist between the  $I(1)$  variables in (4), this system can be written in VECM form as

$$B(L)\Delta Y_t = \Pi Y_{t-1} + \varepsilon_t \quad (5)$$

where  $B(L) = B_0 - B_1L - B_2L^2 - \dots - B_pL^p$  and  $\Pi = \alpha'\beta$  where, as usual,  $\beta$  contains the long run relationship and  $\alpha$  is the vector of adjustment coefficients. However, the  $\alpha$  vector has a number of interesting characteristics in the current specification. First, the elements of  $\alpha$  which correspond to  $I(0)$  variables present in  $Y_t$  represent a levels effect resulting from transforming the system from levels to differences notation (see Dungey and Pagan, 2009), and note that levels effects occur for all  $I(0)$  variables specified in any relationships. Second, and most importantly for the current application, 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 Levchenkova, Pagan and Robertson (1998) and Jacobs and Wallis (2007).

Using the common trends representation, we can write

$$\Delta Y_t = F(L) (B_0)^{-1} \varepsilon_t, \quad (6)$$

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

$$F = \beta_{\perp} [\alpha'_{\perp} B^*(1) \beta_{\perp}]^{-1} \alpha'_{\perp}, \quad (7)$$

where  $B^*(L) = I_{n+k} - B_0^{-1}(B_1 L + B_2 L^2 + \dots + B_p L^p)$  and the orthogonal components  $\alpha_{\perp}$  and  $\beta_{\perp}$  satisfy  $\alpha'_{\perp} \alpha = 0$ ,  $\beta'_{\perp} \beta = 0$ , and hence  $F\alpha = 0$ ,  $\beta' F = 0$ . Following Pagan and Pesaran (2009), if the first  $(n-r)$  shocks are permanent then

$$\Delta Y_t = F(L) B_0^{-1} \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix}, \quad (8)$$

and for the shocks  $\varepsilon_{2t}$  to be transitory requires

$$F B_0^{-1} \begin{pmatrix} 0_{(n-r) \times r} \\ I_{r+k} \end{pmatrix} = F\alpha = 0. \quad (9)$$

Using an eigenvalue decomposition of  $F$ , Pagan and Pesaran (2009) show that the restrictions in (9) imply that  $\alpha_1 = 0$ , where  $\alpha_1$  is the  $(n-r) \times r$  matrix of adjustment coefficients of 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 it in the case of permanent ones.

Further, from (8), the permanent component of  $Y_t$  can be written as

$$\Delta Y_t^P = J \varepsilon_t, \quad (10)$$

where  $J = F B_0^{-1}$  and  $\beta' J = 0$ . Note that the final  $k$  rows of  $J$  are zero, because the  $k$  stationary variables have zero permanent component by definition. Given (10), the VECM can be transformed to a "gaps" form, where the transitory component of the variables are denoted as  $\tilde{Y}_t = (Y_t - Y_t^P)$ . Therefore, as in

Dungey and Pagan (2009), the transitory/permanent decomposition of (5) can be written as

$$B^*(L)\Delta\tilde{Y}_t = \alpha^*\beta'Y_{t-1} - \sum_{j=1}^{p-1} B_j^*\Delta Y_{t-j}^P + B_0^{-1}\varepsilon_t \quad (11)$$

where  $\alpha^* = B_0^{-1}\alpha$ . An important implication of (11) 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. However, (11) shows that the error correction terms 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 (11) by using differences in conjunction with the error correction terms. More specifically, with the exception of the equations for the  $I(1)$  variables that are assumed to be the sources of the permanent shocks, wherever conventional New Keynesian macroeconomic theory would indicate the use of an output gap variable, we include the corresponding differenced output variable and the error correction term(s) from  $\beta'Y_{t-1}$  involving this variable.

One final point concerns the computation of impulse responses. Substituting (10) into (11) leads to

$$B^*(L)Y_t = \alpha^*\beta'Y_{t-1} - B^*(L)J\varepsilon_t + B_0^{-1}\varepsilon_t, \quad (12)$$

which can be written in an autoregressive-moving average form as

$$G(L)Y_t = J(L)\varepsilon_t, \quad (13)$$

where  $G(L)$  is the same matrix as in (4). Impulse response functions can be computed in the usual way through (13), in which long run effects impact through the presence of the  $J$  matrix.

### 3.2 VECM Specification

In the current application, we define  $Y_t = \{y_t^*, \pi_t^*, i_t^*, y_t, \pi_t, i_t, q_t\}$ , where the \* variables now refer to the US and the unstarred variables to the Euro Area. We exploit the existence of a single long run cointegration relationship between the  $I(1)$  variables  $y_t$ ,  $y_t^*$  and  $q_t$  given by

$$y = \beta_0 + \beta_1 y^* + \beta_2 q, \quad (14)$$

which can be viewed as a long run open economy IS relationship analogous to (1)<sup>2</sup>. Although the order of integration of inflation and nominal interest rates is sometimes debated, our specification assumes that these variables are  $I(0)$ , 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, the system (5) contains  $(n-r) = 2$  permanent shocks and  $k+r = 5$  transitory ones.

The two permanent shocks are assumed to originate in the US and Euro Area output variables,  $y_t^*$  and  $y_t$ , representing two distinct technology shocks. While theoretical international models typically assume common technology shocks across economies, this does not seem to be empirically supported by the consistent deviations between growth rates experienced by different countries. Indeed, Uhlig (2009) recently finds differences in technological innovations to be the primary explainer for different monetary policy outcomes in the Euro Area and the US. Further, the assumption of distinct technology shocks is more palatable than considering exchange rate shocks as permanent; see also Dungey and Fry (2008) and Dungey and Pagan (2009). Consequently, the real exchange rate acts as a long run buffer to the effects of the distinct permanent shocks that impact on output in these countries.

The responses of the real exchange rate are captured by the general specifi-

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<sup>2</sup>There is little empirical evidence of cointegration between US and Euro area output when the real exchange rate is excluded from this longrun relationship, or when  $\beta_1$  is set to unity.

cation

$$\begin{aligned} \Delta q_t = & \phi_1(L)\Delta y_t^* + \phi_2(L)\Delta y_t + \phi_3(L)\pi_t^* + \phi_4(L)\pi_t + \phi_5(L)r_t^* + \phi_6(L)r_t \\ & + \phi_7(L)\Delta q_{t-1} + \phi_8 ecm_{t-1} + \varepsilon_{t,e} \end{aligned} \quad (15)$$

and hence we allow  $q_t$  to be influenced by the contemporaneous values of all (foreign and domestic) endogenous variables in the model. This is clearly much more general than a UIP condition, but it reflects the role of the real exchange rate in adjusting not only to the long run relationship of (14) and also 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).

As indicated by the discussion of the previous subsection, equations defining permanent shocks cannot include error corrections in (5). Therefore, to maintain stationarity of all variables and to exclude an error correction term, the IS curve of (1) must be written in terms of  $\Delta y_t$  and  $\Delta y_t^*$ , rather than output gap variables. In all other cases, the implications of (11) are recognised by replacing the output gap  $\tilde{y}_t$  in (2) and (3) by  $\Delta y_t$  and the disequilibrium from (14), with the corresponding representation for  $\tilde{y}_t^*$ , since (as in Dungey and Pagan, 2009, and Dungey and Fry, 2008) output gap effects in these equations are captured by "correcting" output growth through the inclusion of error correction terms. Placing the adjustment coefficients to the single cointegrating relationship in the first column of  $\alpha'$ , this implies  $\alpha_{11} = \alpha_{41} = 0$  and  $\alpha'$  has the form

$$\alpha' = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ \alpha_{21} & \alpha_{22} & 0 & 0 & 0 \\ \alpha_{31} & \alpha_{32} & \alpha_{33} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \alpha_{51} & 0 & 0 & \alpha_{54} & 0 \\ \alpha_{61} & 0 & 0 & \alpha_{64} & \alpha_{65} \\ \alpha_{71} & \alpha_{72} & \alpha_{73} & \alpha_{74} & \alpha_{75} \end{bmatrix} \quad (16)$$

with the first row of  $\beta$  containing the coefficients of the cointegrating vector. The remaining four columns of (16) result from writing the  $I(0)$  variables in first difference form in (5). That is, for computational convenience, we can write any stationary variable  $x_t$  as  $x_t = \Delta x_t + x_{t-1}$ , and the corresponding four

rows of  $\beta$  are pseudo cointegrating vectors corresponding to the levels terms for the  $I(0)$  variables (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 (5) is innocuous.

While a standard VECM would use a Cholesky decomposition of the covariance matrix to impose macroeconomic structure on the model and include lag effects for all variables, a number of additional restrictions are imposed here to reflect the structure of each economy as specified in (1) to (15). Additionally, the variable ordering and contemporaneous matrix restrictions reflect the New Keynesian view that contemporaneous international linkages apply through output only, with no direct linkages through inflation and interest rates. To be specific, our matrix of contemporaneous effects can be represented as

$$B_0 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ b_{21}^0 & 1 & 0 & 0 & 0 & 0 & 0 \\ b_{31}^0 & b_{32}^0 & 1 & 0 & 0 & 0 & 0 \\ b_{41}^0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & b_{54}^0 & 1 & 0 & 0 \\ 0 & 0 & 0 & b_{64}^0 & b_{65}^0 & 1 & 0 \\ b_{71}^0 & b_{72}^0 & b_{73}^0 & b_{74}^0 & b_{75}^0 & b_{76}^0 & 1 \end{bmatrix}. \quad (17)$$

Within each economy, (17) reflects the usual variable causal ordering, as in (1) to (3). Further, the restriction  $b_{14}^0 = 0$ , while  $b_{41}^0$  is unrestricted, implies that business cycle co-movements originate in the US economy, reflecting evidence found in empirical studies that US output growth 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 lag matrices also reflect these conditions, but allow additional dynamics, with

$$B_L(L) = \begin{bmatrix} b_{11}^L & b_{12}^L & b_{13}^L & b_{14}^L & 0 & 0 & b_{17}^L \\ b_{21}^L & b_{22}^L & 0 & 0 & 0 & 0 & b_{27}^L \\ b_{31}^L & b_{32}^L & b_{33}^L & 0 & 0 & 0 & 0 \\ b_{41}^L & 0 & 0 & b_{44}^L & b_{45}^L & b_{46}^L & b_{47}^L \\ 0 & 0 & 0 & b_{54}^L & b_{55}^L & 0 & b_{57}^L \\ 0 & 0 & 0 & b_{64}^L & b_{65}^L & b_{66}^L & 0 \\ b_{71}^L & b_{72}^L & b_{73}^L & b_{74}^L & b_{75}^L & b_{76}^L & b_{77}^L \end{bmatrix} \quad (18)$$

where  $B(L) = B_0 + B_L(L)$  and all nonzero elements of  $B_L(L)$  on the right-hand side of (18) are scalar polynomials (for powers 1 to  $p$  inclusive) in the lag operator. Cross-country restrictions in  $B_L(L)$  are symmetric and reflect the specifications of (1) to (3) above. Specifically, with the exception of the IS equations, all cross-country effects are specified as zero in (18). However, US output growth impacts directly on Euro area output via coefficient  $b_{41}^L$ , while the converse applies through  $b_{14}^L$ . Thus, although the contemporaneous relationship in (17) is unidirectional, the coefficient  $b_{14}^L$  allows Euro Area output changes to have spillover effects on the US output.

It should be noted that the zero restrictions in the  $B_L(L)$  matrices do not statistically ensure the mutual orthogonality of the shocks, particularly across countries. This may or may not be an issue of practical importance, and will be assessed in the empirical application. The empirical implementation of the system given by (14) to (18) proceeds in a similar way to Dungey and Pagan (2009) and Dungey and Fry (2008). That is, a two-step procedure is used, with the longrun cointegrating relationship estimated first, and the remaining seven equations estimated conditional on the longrun coefficients.

## 4 Data

The Euro Area data for the empirical application are drawn from the updated Area Wide Model (AWM) database (originally developed within the European Central Bank by Fagan, Henry and Mestre, 2005 and updated to 2007Q4 on <http://www.eabcn.org>), together with extensions to that database discussed in Anderson, Dungey, Osborn and Vahid (2008). The US data are drawn directly from the FRED database.

Euro Area real GDP is from the November 2008 release of the AWM database. The AWM database does not contain a backdated bilateral (real or nominal) exchange rate for the euro with the US dollar. Lubik and Schorfheide (2005) adopt the fixed GDP weights of the real variables in AWM to construct exchange rates prior to the introduction of the euro. However, this is not very

appealing as it tends to overweight the contributions of countries such as Italy and Portugal in the early parts of the sample, when these countries did not follow disciplined monetary policy as (for example) in Germany. Therefore, we adopt data calculated from the sliding weight mechanism developed by Anderson et al (2008) until the end of 1998, after which the series becomes the observed bilateral exchange rate. The exchange rate is expressed as US dollars per one euro. The Euro Area interest rate is represented by the 3 month Euroibor rate from the beginning of 1992, and prior to that is constructed using the methodology of Anderson et al (2008). The Euro Area annual inflation rate is represented by the Euro Area HICP inflation rate from February 1994, and prior to that is again constructed using the sliding weights approach of Anderson et al (2008). The inflation rates are used to construct price indices from which the real exchange rate is defined. Full data sources and details are given in the Appendix.

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. The model is estimated using 3 lags in the levels of all variables, corresponding to two lags when expressed in changes.

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 appears to support the proposition of Ciccarelli and Mojon (2009) that inflation is, to a large extent, a global phenomenon.

## 5 Closed Economy Specification

To set a benchmark for the performance of the model specified in Section 3, we first present the results from standard closed economy SVAR models for the Euro Area and the US economies separately. In these specifications each country is represented by four variables, namely domestic output, inflation and interest rates, together with the (bilateral) exchange rate. The model is a standard VAR, with the structure of equations (1) to (3) plus (15). However, as closed economy models, foreign output is excluded from (1), while no foreign variables enter (15). Further, the closed economy set-up precludes using cointegration between domestic and foreign output (and the exchange rate) to account for the I(1) nature of the output and exchange rate data. Instead, as in many empirical applications, the I(1) variables  $y_t$  and  $q_t$  are transformed to stationarity by first differencing. Thus the estimated system in each case is an SVAR(2) in  $\Delta y_t, \pi_t, i_t$  and  $\Delta q_t$ . Variables are defined in the same way for each country (so that in both cases an increase in the exchange rate represents an appreciation of the Euro relative to the US dollar). The individual country models reflect a closed economy IS curve, Phillips curve and Taylor rule, while the exchange rate reacts to all variables in the model.

The results display a number of features and problems inherent in the existing literature. Although we do not present full results, Figure 1 presents selected impulse response functions, together with bootstrapped 2 standard deviation error bands, relating to the monetary policy nexus represented by interest rates and inflation. The shock sizes applied are identical to those used in the open economy model documented in Section 6, to ease later comparison. In particular, panels (a) and (b) show the interest rate response in each country to (own) inflation shocks, while panels (c) and (d) illustrate the response of inflation to interest rate shocks. Considering first the impact of inflationary shocks, panel (a) shows that the effect in the Euro Area is to cause interest rates to decrease from 6 months after the shock, while a US inflationary shock, panel (b), causes interest rates to increase for 2 years, after which they decline until some 7 years

after the initial shock. The patterns of these essentially negative interest rate responses are not plausible. Further, the confidence bands are very wide, indicating a great deal of uncertainty in the model about the response two to three years after the shock.

Monetary policy shocks are typically represented by shocks to the domestic interest rate, with Figure 1 panels (c) and (d) presenting the effects of domestic interest rate shocks in both economies. Here, despite allowing for exchange rate effects, the price puzzle is evident in both countries, albeit the effects are small and insignificant. Although Giordani (2004) has demonstrated the possibility that the price puzzle may be eliminated by the use of output gap rather than output levels, this will not be as important here as output growth (and not levels) is employed.

Although the responses to output shocks in the closed economy specifications are broadly as anticipated (namely, both inflation and interest rates rise), the effects of inflation shocks and monetary policy shocks do not provide an appealing characterisation of the behavior of either economy. Therefore, we now proceed to consider the implications of the open economy specification, as set out in Sections 2 and 3.

## 6 Open Economy 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 (in logs) and the real exchange rate. Testing for cointegration between these three variables in a system framework supports the presence of one cointegrating vector<sup>3</sup>. However, it is convenient for our analysis to estimate this vector as the first step of the Engle-Granger procedure, which yields

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<sup>3</sup>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.

Table 1: Residual correlations

	$y_t^*$	$\pi_t^*$	$r_t^*$	$y_t$	$\pi_t$	$r_t$	$q_t$
$y_t^*$	1.00						
$\pi_t^*$	.008	1.00					
$r_t^*$	-.001	-.003	1.00				
$y_t$	-.002	.111	-.030	1.00			
$\pi_t$	-.086	.626	.026	.045	1.00		
$r_t$	.084	.009	.061	-.003	-.010	1.00	
$q_t$	-.029	-.020	.031	-.031	-.022	.021	1.00

$$y_t = 0.7323y_t^* + 0.0362q_t + 7.3708. \quad (19)$$

Note the inclusion of a constant in (19), which in this case includes a representation of the differential rates of population growth in the two economies, as well as providing a measure of conditional rather than absolute convergence.

## 6.1 Diagnostics

Prior to computing the impulse response functions associated with the international system described above, it is informative to examine first the behaviour of the residuals. In particular, as noted in Section 3, our SVECM specification does not guarantee the orthogonality of the shocks in the system, although such orthogonality is assumed in the impulse response analysis.

The correlations of the residuals for the estimated system are shown in Table 1. While it is evident from Table 1 that most of the residuals 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. 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 inflation to the system does not serve to reduce this problem.

To account for this correlation, we allow a direct transmission of inflationary shocks between the two economies by allowing the US inflation rate to enter directly into the Euro Area Phillips curve, both contemporaneously and with lags. Further, in an analogous way to the cross-country effects permitted for short run output fluctuations, lags of the Euro Area inflation rate are permitted to enter the US Phillips curve relationship. Consequently, compared with the matrices specified in (17) and (18) above, we permit  $b_{52}^0 \neq 0$ ,  $b_{52}^L \neq 0$  and  $b_{24} \neq 0$ , as well as acknowledging the levels effects of the inclusion of these variables in the Phillips curves by amending the matrix  $\alpha'$  in (16) to reflect non zero values of  $\alpha_{24}$  and  $\alpha_{52}$ . Although we do not offer a full theoretical justification for the relaxation of these restrictions, it is possible that inflationary experiences in other countries influence domestic inflationary expectations.

With these changes, the correlation matrix of the residuals is reduced to that given in Table 2. As can be seen, the correlation between the two inflation rates is now reduced to 0.020 while almost all other correlations are below 0.08 in absolute value, which is not inconsistent with the orthogonality assumption. Incidentally, despite the relatively high correlation between the interest rate series for the two economies, the domestic monetary policy reaction functions do a good job of taking account of this, as seen by the small residual correlation between  $r_t^*$  and  $r_t$  in both Tables 1 and 2. Of course, the closed economy models examined in Section 5 do not, by their nature, allow for any common international inflationary influences. The need to capture such effects is a further inadequacy of closed economy specifications.

## 6.2 Impulse Response Analysis

Impulse response results are presented only for the model extended to take account of direct cross-economy inflation effects. All shocks are set equal to one standard error for the post-1983 sample, and Table 3 presents these standard errors. Consider first the responses of shocks originating in a particular economy

Table 2: Residual correlations with inflation interactions

	$y_t^*$	$\pi_t^*$	$r_t^*$	$y_t$	$\pi_t$	$r_t$	$q_t$
$y_t^*$	1.00						
$\pi_t^*$	-0.004	1.00					
$r_t^*$	0.024	0.014	1.00				
$y_t$	0.010	0.100	-0.003	1.00			
$\pi_t$	0.057	0.020	0.069	0.046	1.00		
$r_t$	0.083	-0.003	0.037	-0.005	-0.006	1.00	
$q_t$	-0.031	-0.027	0.032	-0.030	0.021	0.022	1.00

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

Variable	Size	Variable	Size
$y_t^*$	0.4607%	$y_t$	0.4256%
$\pi_t^*$	0.4967 p.a.	$\pi_t$	0.2238 p.a
$r_t^*$	32.79 basis pts	$r_t$	29.50 basis pts
		$q_t$	3.7093%

on the variables of that same economy. Figure 2 shows the impulse responses for the Euro Area variables to shocks originating in the Euro Area, and Figure 3 shows the corresponding results for the US. Bootstrapped 2 standard deviation error bands, estimated using a static bootstrap with 5000 draws from the estimated VAR residuals with replacement, are also shown in each figure.

Shocks to Euro Area and US output, Figures 2(a) and 3(a), are permanent and we interpret these as productivity shocks. (In contrast, the output shocks in the closed economy model are temporary.) In both cases, a permanent shock to technology leads to both inflation and interest rate rises, as anticipated, see Figures 2 (b and c), 3 (b and c). Although inflation and interest rates are stationary, the technology shock has long-lasting effects on these variables, notwithstanding that the responses of Euro Area inflation are modest and zero lies towards the centre of the confidence bands. The temporary Euro Area inflation shock, Figure 2(e), has a short run positive effect on output, but ultimately leads to lower

output, although most of these effects are not statistically significant, Figure 2(d). Higher inflation leads immediately to higher interest rates, although this dies out after about six years and interest rates are subsequently marginally lower than in the absence of the shock, Figure 2(f). The monetary policy shock of higher interest rates results in the anticipated decline in inflation, Figure 2(h), although the effect is insignificant. Overall, therefore, this open economy SVECM delivers the anticipated responses for key Euro Area variables.

The responses of US variables to inflation and monetary policy shocks are broadly similar to the Euro Area case. However, the inflationary shock has a more marked and significant effect on interest rates in Figure 3(f) compared with Figure 2(f), perhaps reflecting the more established nature of US monetary policy compared with that for the Euro Area over this period (in which area-wide policy was not fully established). Although output initially declines in response to a US inflation shock, Figure 3(f), and then becomes slightly positive, both of these are insignificant. The monetary policy shock shown in figure 3(i) results in an (insignificant) fall in inflation, and a very small and insignificant one year fall in output. There is no evidence of a price puzzle for either economy. The nature of the domestic intereactions, particularly the response of interest rates to inflation shocks, is more satisfactory than in the closed economy case of Section 5.

Figure 4 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 technology (output) leads to an increase in Euro Area output, Figure 4(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, Figures 4(b and c). In contrast, 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 delay of around a year for inter-

est rates. US monetary policy shocks cause an insignificant rise in Euro Area output, due to the associated depreciation of the euro and consequent rise in Euro Area exports and inflation, Figures 4(g and h) and thus a monetary policy response in the form of higher domestic interest rates, Figure 4 (i).

US variable responses to Euro Area shocks, shown in Figure 4, exhibit few cases that are significant according to the confidence bands. Nevertheless, while Euro Area technology shocks have relatively little impact on US output or inflation, Figures 5 (a and b), their effects are sufficient to result in a fall in US interest rates, Figure 5(c). Of particular interest is the asymmetric response of the different countries to inflation shocks sourced internationally. While higher US inflation lead to a temporary increase in Euro Area output, higher Euro Area inflation has the opposite effect on US output, Figure 5(d). Nevertheless, and despite the contemporaneous inflationary effects being specified as unidirectional from the US to the Euro Area, the US experiences spillovers of Euro Area inflation, Figure 5(e). Further, an increase in Euro Area interest rates results in a fall in US output, Figure 5(g), which comes about because the associated depreciation of the US dollar is not sufficient to stimulate net exports to the Euro Area to overcome the reduction in demand emanating from Europe due to the tighter monetary policy; contrast Figures 4(g to i) with 5(g to i), and see also Figures 6 (a and b).

The impulse responses of the real exchange rate to each of the shocks in the system are entirely as expected, Figures 6(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 6(c), and a similar effect on Euro Area output, Figure 6(f). Although one would expect that the output effects should be opposite as one country experiences a depreciation 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 is shown in Figure 4(a). The inflationary effects of exchange rate shocks are larger for the Euro Area, Figure 6(g) than the US, Figure 6(b), but insignificant in both cases. 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 an insignificant effect on the interest rates in both regions. However, the lower output and inflation in the Euro Area shown in Figures 6(f and g) are consistent with the lower Euro Area interest rates shown in Figure 6(h).

It is clear from these results that the inclusion of open economy effects can lead to discernible differences in the analytical results from closed economy representations. In Section 5 the cross country effects were constrained to zero, but on relaxing those restrictions the evidence supports substantial and in some cases significant cross country impacts. These impacts flow through sufficiently that domestic responses to domestic sourced shocks are also affected. The extension to an open economy case where shocks flow between both countries takes a further step to empirically revealing the richness and complexity of the underlying economic relationships.

## 7 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, where the Euro Area is an open economy which receives substantive effects from a dominant economic entity, the US. However, the Euro Area economic shocks are also influential, to at least some degree, on outcomes in the US. The conduit for achieving a limited openness model is particularly the recognition of reversion towards the long run restrictions present in the theoretical structure of New Keynesian models such as Gali and Monacelli (2005) and Monacelli (2005). Implementation of both short and long run restrictions, using the methods of Pagan and Pesaran (2009) , give the empirical representation of the theoretical model a

greater ability to represent the data than previously achieved. Additionally, the approach has the advantage of distinguishing permanent and transitory shocks in a single empirical framework.

An important finding in the paper is that an identification scheme broadly justified using modern New Keynesian theory results in uncaptured common inflationary correlations between the two regions. By allowing for direct interactions between the inflation rates of the two regions in the empirical specification we obtain a more empirically acceptable specification. Theoretical models may need to consider means by which foreign inflationary shocks can be more directly incorporated into the price formation of the domestic economy.

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## 8 Appendix: Details on 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, 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.

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 Euro-ibor.

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: Impulse responses for closed economy models.

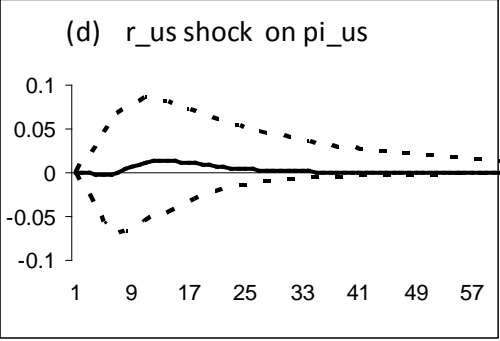
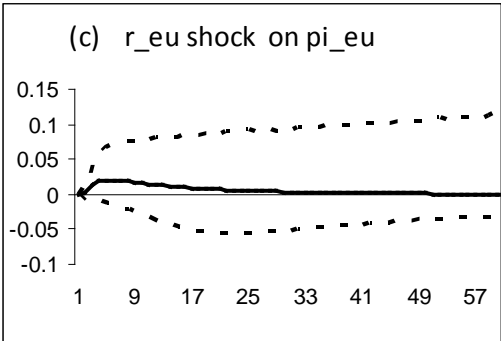
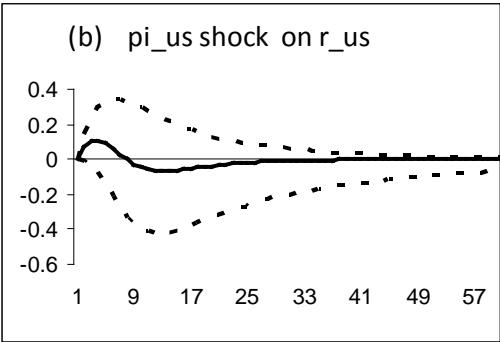
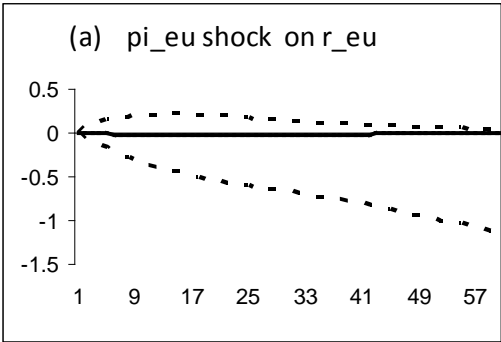


Figure 2: Impulse responses for Euro Area variables to Euro Area shocks

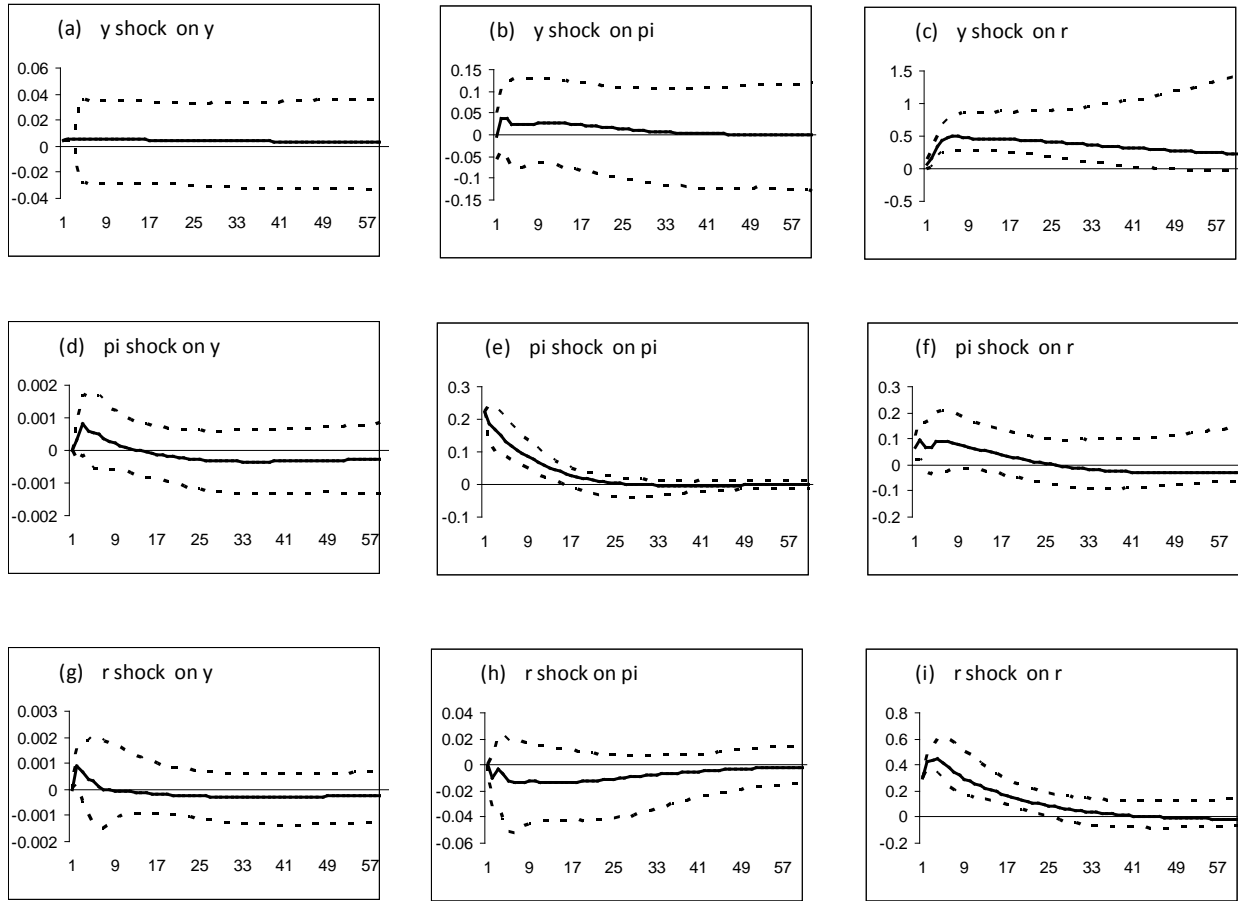


Figure 3: Impulse responses for US variables to US shocks

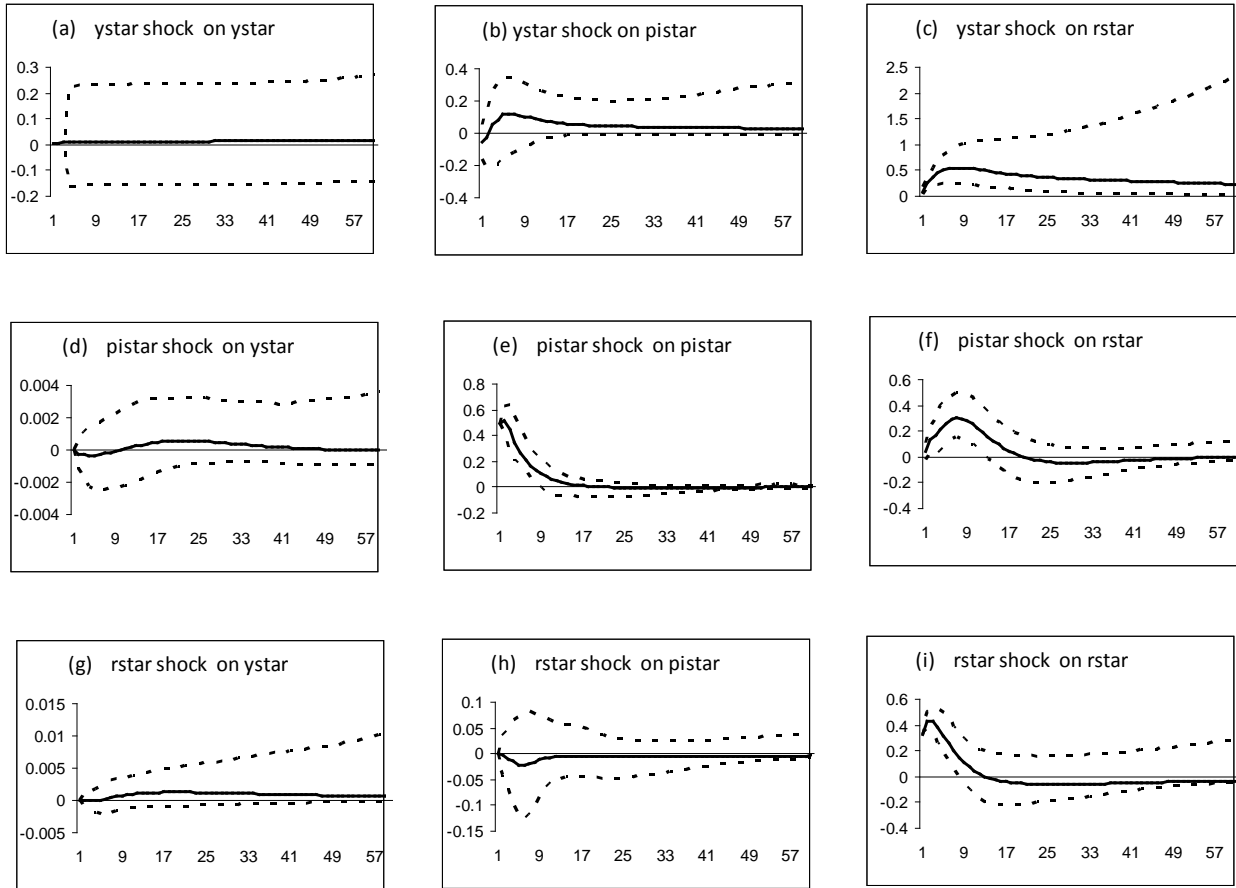


Figure 4: Impulse responses for Euro Area variables to US shocks

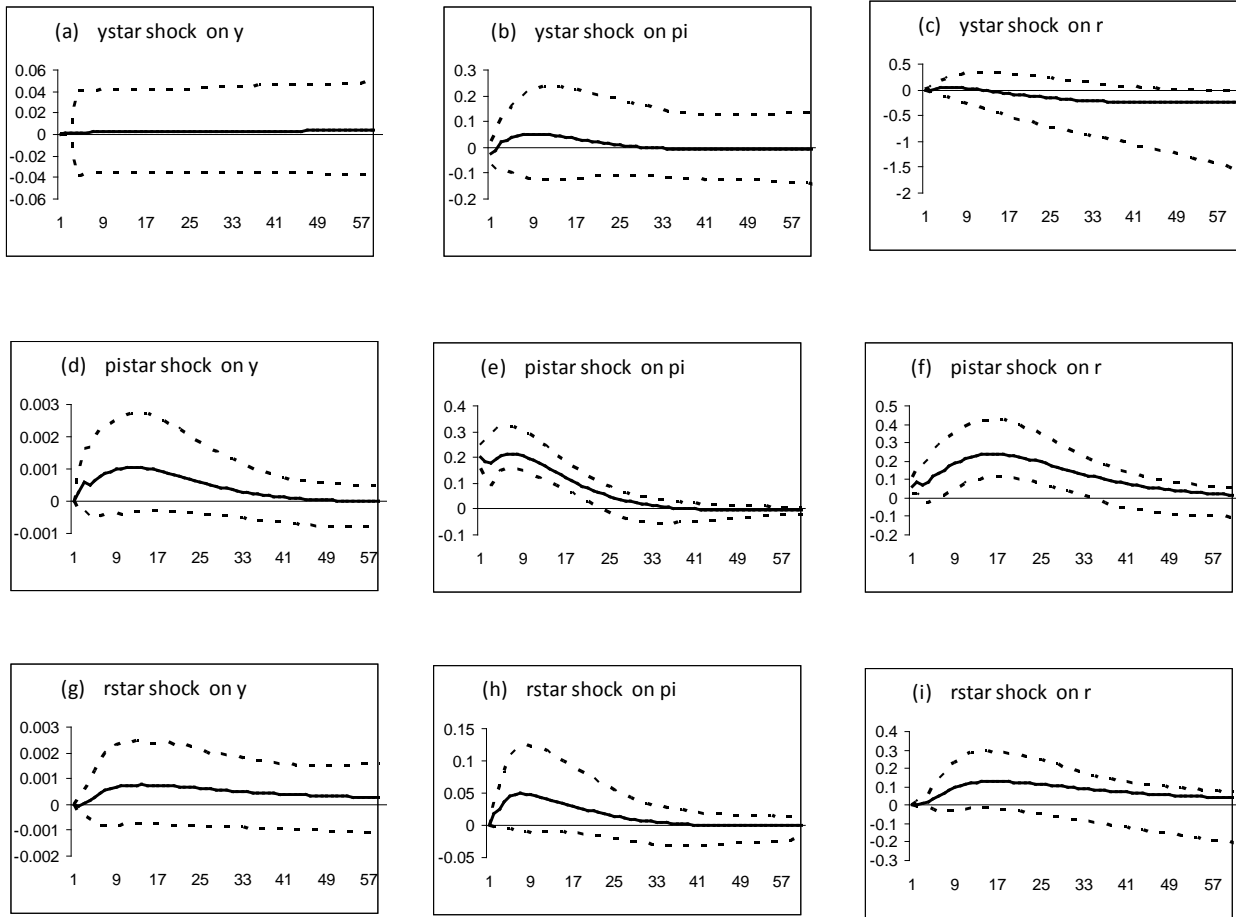


Figure 5: Impulse Responses for US variables to Euro Area shocks

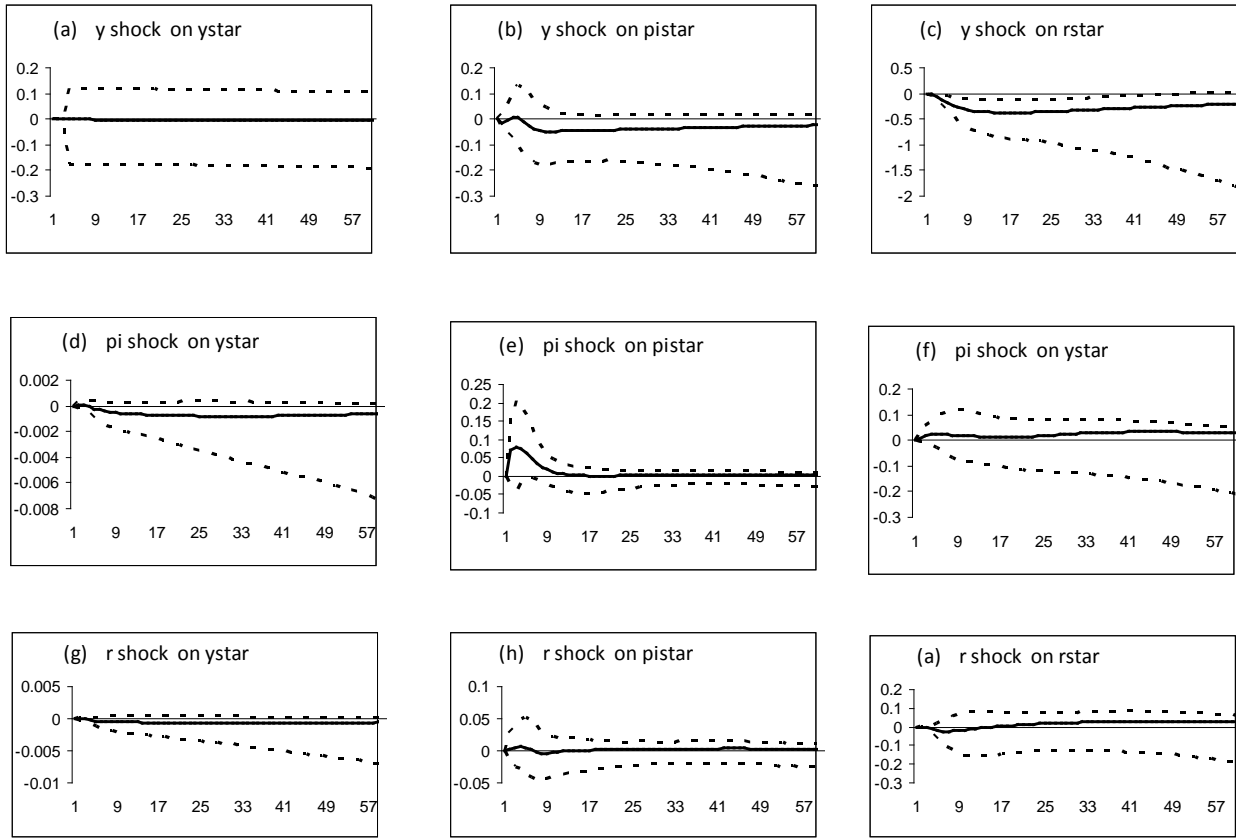


Figure 6: Impulse responses involving the exchange rate. (a)-(b) represent the impact of shocks in interest rates on the exchange rate, (c)-(i) represent the impact of a shock in the exchange rate on US and Euro Area variables.

