Modelling large open economies with international linkages: The US and Euro Area*

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Abstract

Empirical modelling of the international linkages between the Euro Area and the US requires an open economy specification. This paper allows for dynamic and long run relationships between economies with mixed I(0) and I(1) data, and recognises that a means of achieving identification for such a model in a VAR framework is to restrict only the contemporaneous relationships between some variables across the economies. We denote these as predominance assumptions. Introducing variable by variable orderings in a VAR, rather than traditional country by country orderings, emphasises that predominance assumptions may vary between different variables. We estimate the model for the US and Euro Area economies for alternative predominance assumptions concerning output and inflation. While the output predominance assumption has little effect and domestic responses to domestically sourced inflation shocks are not affected by the inflation predominance assumption, inflation predominance does influence domestic monetary policy response to foreign inflation shocks.

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1 Introduction

Empirical modelling of the world's largest economies, the US and the Euro Area, needs to take account of the interactions between them[1]. This paper provides an empirically coherent VAR structure which allows direct feedbacks between both countries, rather than relying on implausible country based exogeneity assumptions. To achieve this, we introduce variable ordering for multi country VAR models which has the advantage of clarifying the identification choices for international linkages in different variables, such as output and inflation, while retaining the ability to maintain standard identification structures within each economy. Bayoumi and Swiston (2009, p.356) make the point that there are a number of domestic economic relationships about which we are relatively comfortable, such as "easily adjustable interest rates adjust to more slow-moving inflation and output", but that the cross economy linkages between output and inflation are less easily determined *a priori*. Our solution is to introduce the concept of contemporaneous dominance, denoted predominance, within some variables across economies. For example, it may be plausible to assume that US output is predominant over Euro Area output, which means that contemporaneous shocks to US output transmit to Euro Area output contemporaneously, but shocks in Euro Area output transmit to the US only with a lag. Further linkages between the economies can be captured directly by including long run cointegrating relationships, where responses to deviations from these relationships provide a further feedback cross-economy mechanism. As the standard set-up for macroeconomic models includes both $I(1)$ and $I(0)$ data (output, inflation and interest rates) we show how this is incorporated in the modelling framework, and determine the sources of permanent and temporary effects.

The main contributions of the paper are the introduction of variable ordering and the associated use of predominance assumptions to provide cross economy identification. In our application to the US and Euro Area the benchmark model assumes predominance of US output over Euro Area output and of US inflation

[1] Together the US and Euro Area make up some 35% of total world GDP in 2009 (figures taken from ECB available at http://www.ecb.int/mopo/eaec/html/index.en.html).

over Euro Area inflation. The first of these, that the US output is predominant, is well-supported in the literature, see for example Bayoumi and Swiston (2009), Perez, Osborn and Artis (2006). Although Ciccarelli and Mojon (2008) provide evidence of the global nature of inflation and strong inflation linkages are empirically supported by Dees, Pesaran, Smith and Smith (2009), the predominance of US inflation over Euro Area inflation is less clear. For example, although Galesi and Lombardi (2009) provide supporting evidence for this assumption, evidence to the contrary can be found in Bataa, Osborn, Sensier and van Dijk (2009).

An important advantage of our proposed method is that it is not necessary to have one economy predominant in all cross economy linkage variables. To illustrate the alternatives we conduct experiments varying the predominance assumptions in the model, and find that while inflation predominance matters for the responses of domestic variables to foreign shocks in either country, the output predominance assumption has very little effect. These output results are consistent with those of Bayoumi and Swiston (2009).

Focussing on monetary policy shocks, our results show that the predominance assumptions have little impact on the responses of domestic interest rates to domestically soured inflation shocks - placing credence on the claim that central banks respond only to domestic conditions. However, inflation predominance assumptions make a substantial difference to monetary policy responses to foreign sourced inflation shocks. In particular, when the foreign economy is inflation predominant, domestic interest rate responses to foreign inflation are larger. Thus the source of the inflation shock and, in the case of foreign shocks how fast it is expected to transmit to the domestic economy, make a difference to monetary policy responses.

The methodology we propose provides an alternative means of empirically linking multiple economies within an vector autoregressive (VAR) framework to the factor approach in Canova and Ciccarelli (2009), the assumption of a single dominant unit in Pesaran and Chudik (2010), or the GVAR approach of Dees, Di Mauro, Pesaran and Smith (2007). Our approach has a similar flavour to elements of the last two of these, explicitly considering adjustment to long run cross-country relationships within a common framework (like the GVAR) and providing a framework to exploit information about the nature of cross-country effects. However, whereas Pesaran and Chudik (2010) examine the implications of one economy among many being dominant, and hence retaining its influence as the number of economies increases, we consider two (or more) large economies and investigate assumptions about the sources of shocks. An important advantage of our approach is that different economies may be predominant for different variables.

The paper proceeds as follows. First, we present our methodology in Section 2, where we elucidate our concept of predominance and variable based ordering, while also showing how to capture mixed order $I(1)$ and $I(0)$ variables with potential cointegrating relationships among the former. Section 3 applies this methodology to a model containing both the US and Euro Area economies. Baseline results where US predominance is assumed for both output and inflation are shown to give a sensible account of domestic relationships, and a first insight into the strength of cross economy shocks in Section 4. The sensitivity of the model outcomes to the predominance assumptions are examined in a series of experiments in Section 5 where the main finding is that inflation predominance has a much greater impact on model results than output predominance. A final section concludes, with further details of the model and data being provided in the appendices.

2 Methodology

An innovation of the current paper is to consider the implications of identifying a VAR for multiple countries through different assumptions as embedded in variable orderings. Rather than country based ordering, where the variables are listed by country, we introduce variable based ordering, where variables across different countries are listed by variable type. This has the important advantage of separating the different aspects of the interrelationships between economies that are exhibited by different variables, such as inflation, output or financial links. There is no necessary reason, for example, to impose that one country is always predominant in every international relationship across all periods.

In the context of small open economy models, the literature often (and plausibly) imposes exogeneity for the US, such as Dungey and Pagan (2009) for Australia and Cushman and Zha (1997) for Canada. Alternatively, an exogenous trade-weighted foreign sector is employed for New Zealand in Buckle *et al.* (2007) and for Switzerland in Assenmacher-Wesche and Pesaran (2008), while the GVAR structure is used to examine the UK and Sweden in Pesaran, Smith and Smith (2007). Studies of EU Accession countries, such as that of Orlowski (2005) for inflation in the Czech Republic, Poland and Hungary, often treat the Euro Area as exogenous. On the other hand, a multitude of papers treat the US economy as closed, while a number of papers for the Euro Area also proceed without considering international effects, for example Smets and Wouters (2005) and van Aarle, Garretson and Gobbin (2003).

However, when considering larger economies, where there is no clear exogeneity assumption between them, a different strategy may be usefully employed.

2.1 Variable Based Ordering and Predominance

A conventional VAR(p) model may be written as

$$G(L)Y_t = u_t \tag{1}$$

where Y_t is comprised of n blocks of variables X_{it}, $i = 1...n$, with each block X_{it} an $m \times 1$ vector of observations on a particular variable for each of m economies considered in the system,[2] so that

$$Y_t = \begin{bmatrix} X_{1t} \\ X_{2t} \\ .. \\ X_{nt} \end{bmatrix}$$

[2] For notational simplicity we give the case where all blocks X_{it} contain the same number of variables, m, but generalizing to allow for each X_{it} to have dimension m_i which varies with i is straightfoward.

where the elements of each X_{it} are ordered by country and $G(L) = I_{nm} - G_1 L - ... - G_p L^p$ with I_{nm} an $nm \times nm$ identity matrix. Corresponding to these blocks, also define $u_t = (v'_{1t}, v'_{2t}, ..., v'_{nt})'$ in (1), where each v_{it} is $m \times 1$. In general, the disturbances in (1) satisfy $E[u_t u'_t] = \Sigma$, where Σ is an $nm \times nm$ positive definite covariance matrix. Identification conditions are sought that define a matrix P, such that $Pu_t = \varepsilon_t$ with $E[\varepsilon_t \varepsilon'_t] = \Omega$ in which Ω is a diagonal matrix. Therefore, the elements of ε_t are the orthogonal shocks to the system.

Although various types of restrictions can be used to provide identification, it remains common practice in empirical work to employ a Cholesky decomposition for this purpose. However, in a cross-country setting, and where variables are ordered by type, economic theory may provide the causal ordering across blocks X_{it} (and hence across v_{it}), but does not provide such information within the X_{it} blocks of Y_t.When modelling the relationship between a small open economy (such as Canada) and its major influence (such as the US), the causal ordering within blocks is straightforward. However, this is not the case when modelling the interrelationships between two or more large open economies, in our case the US and Euro Area; see Bayoumi and Swiston (2009).

To facilitate this discussion, we introduce the term predominance to indicate the causal ordering within an individual X_{it} vector. Consider a particular $m \times 1$ block, X_{it}, with elements denoted $x_{j,it}$, $j = 1, ..., m$, (for example the inflation rates for each of m economies) so that

$$X_{it} = \begin{bmatrix} x_{1,it} \\ x_{2,it} \\ .. \\ x_{m,it} \end{bmatrix}.$$

Then predominance of economy d over economy j $(d, j \in m)$ in block i implies that the contemporaneous values of $x_{d,it}$ are weakly exogenous for $x_{j,it}, j \neq d$. Note that predominance in our sense applies to contemporaneous values only, and allows bilateral feedback in the dynamics. Predominance assumptions provide an identification solution when the (conditional) covariance matrix for X_{it} in (1), namely

$$E[v_{it}v_{it}'] = \Sigma_i \tag{2}$$

is not diagonal.

The predominance ordering for block X_{it} can be represented by the $m \times m$ matrix D_i (whose elements are zeros and ones), such that $D_i X_{it}$ has disturbance vector $D_i v_{it}$ and a Cholesky decomposition applied to this re-ordered vector (namely $P_i D_i v_{it}$) appropriately defines the international sources of shocks for variable type i. An important advantage of the variable based ordering that we propose is that alternative predominance assumptions, D_i and D_j, can be adopted for different blocks, X_{it} and X_{jt}.

For example, in the US/Euro area context, each $X_{it} = (x_{US,it}, x_{EA,it})'$, but if we assume that the US is predominant for output (variable $i = 1$, say) and the Euro Area is predominant for inflation ($i = 2$). Then for the block $D_1 = I_2$, but a re-ordering is required to capture the predominance in inflation, and

$$D_2 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}. \tag{3}$$

This idea readily generalizes to case with $m > 2$ countries. Although Pesaran and Chudik (2010) do not identify a causal ordering among countries, their contemporaneous dominance assumption (Pesaran and Chudik , 2010, Assumption 2) is related to our concept of predominance. More specifically, when Σ_i is not diagonal, and country d is predominant over country j in block i, then the shock $e_{d,it}$ will be a (static) common factor influencing both $x_{d,it}$ and $x_{j,it}$. If, for a specific block i, the covariance matrix (2) is diagonal, then no re-ordering is required, so that the corresponding $D_i = I_m$ and there is no static common factor for the disturbance block v_{it} in (1).

Combining such predominance assumptions with a variable-based causal ordering for the blocks within the vector Y_t, we can define a block diagonal matrix D such that

$$DY_t = \begin{bmatrix} D_1 X_{1t} \\ D_2 X_{2t} \\ .. \\ D_n X_{nt} \end{bmatrix}$$

to which a Cholesky decomposition can be applied to obtain the vector of orthogonal shocks ε_t. By construction, D is an $mn \times mn$ nonsingular matrix.

Note that, with predominance re-ordering, the system of (1) becomes

$$G^*(L)DY_t = u_t \tag{4}$$

where $G^*(L) = G_0^* - G_1^*L - ... - G_p^*L^p$ and $G_i^* = G_iD^{-1}$ $(i = 0, ..., p)$. The corresponding structural VAR model is then obtained by premultiplying (4) by the lower triangular matrix P that achieves the Cholesky decomposition, with orthogonal shocks $\varepsilon_t = D^{-1}PDu_t$.

2.2 Cointegration

Macroeconomic systems frequently include non-stationary $I(1)$ variables, in addition to stationary ones. When such cointegration is present, then a structural VAR system may be written in the standard SVECM form as

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

where $B(L) = B_0 - B_1L - ... - B_{p-1}L^{p-1}$ and Π arises from the cointegrating relationships and error-correction coefficients. If identification is achieved through causal ordering (between variables) and predominance assumptions (within each variable block), as just discussed, then the coefficient matrices in (5) can be obtained from those of (4) and P; in particular, and relevant to our empirical application in the next section, the contemporaneous relationships are given by $B_0 = PD$. However, (5) could also be identified through the imposition of other restrictions.

In order to consider cointegration, we need a notation that picks out the non-stationary variables in the system and the subset of $I(1)$ variables that are the sources of the permanent shocks (Pagan and Pesaran, 2009). Say there are a total of ℓ non-stationary elements[3] in Y_t, with r cointegrating relationships between these, so that the system is driven by $\ell - r$ permanent shocks. In order

[3] Typically, within a block all variables will have the same order of integration. However, this is not necessary or imposed.

to separate these, define the $(\ell - r) \times nm$ zero/one matrix S_1 such that $S_1 Y_t$ contains elements of Y_t that are subject to permanent shocks. Further, define the $r \times nm$ matrix S_2 that similarly picks out the $I(1)$ variables in Y_t that are subject to transitory shocks only.

However, the system may also contain $I(0)$ variables that are (by definition) associated with transitory shocks, and these need to be incorporated in (5). Clearly, there are $nm - \ell$ such variables, and we define S_3, of dimension $(nm - \ell) \times nm$ such that $S_3 Y_t$ contains these variables. Then S, of dimension $nm \times nm$, where

$$S = \begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix},$$

re-orders the elements of Y_t such that SY_t consists of, firstly, the $\ell - r$ individual variables giving rise to permanent shocks, secondly, the r non-stationary individual variables subject to transitory shocks and, finally, the $nm - \ell$ individual variables that are $I(0)$. Clearly, by construction, S is nonsingular. Also note, that for simplicity of exposition, no predominance re-ordering is considered here.

Recognizing the re-ordering of variables through S, rewrite (5) as

$$\begin{aligned} C(L)\Delta(SY_t) &= \Pi^{(C)}(SY_{t-1}) + \varepsilon_t \\ &= \alpha\beta'(SY_{t-1}) + \varepsilon_t \end{aligned} \tag{6}$$

where $C(L) = C_0 - C_1 L - ... - C_{p-1} L^{p-1}$ with $C_i = B_i S^{-1}$ $(i = 0, 1, ..., p-1)$ and $\Pi^{(C)} = \Pi S^{-1}$, while both α and β are $nm \times (r + nm - \ell)$ matrices. The matrix β has the form

$$\beta = \begin{bmatrix} \beta_0 & 0_{\ell \times (nm-\ell)} \\ 0_{(nm-\ell) \times r} & I_{(nm-\ell)} \end{bmatrix} \tag{7}$$

where the $\ell \times r$ submatrix β_0 contain the r linearly independent cointegrating vectors between the first ℓ elements of SY_t and $I_{(nm-\ell)}$ defines dummy variables for the levels of the stationary variables in the system. The matrix α has partitions and zero blocks corresponding to those in β, but here the $\ell \times r$ submatrix α_0 contains the error-correction coefficients while the south east $(nm - \ell) \times (nm - \ell)$

block is a diagonal matrix containing the levels effects for the $I(0)$ variables[4]. Since (6) can be considered as a system in the re-ordered vector SY_t, while ε_t relates to the original variable ordering in Y_t, it is also useful to define the orthogonal shock vector $e_t = S\varepsilon_t$ that orders the shocks as for SY_t.

Using the common trends representation, (6) has moving average form

$$\Delta(SY_t) = F(L)C_0^{-1}\varepsilon_t = F(L)C_0^{-1}S^{-1}e_t \tag{8}$$

where $F(L) = I_{nm} + F_1L + F_2L^2 + \ldots$ and $F(1) = F$. The permanent component of Y_t can be obtained from

$$\Delta(SY_t^p) = Je_t, \tag{9}$$

where $J = FC_0^{-1}S^{-1}$ and $\beta_0'J = 0$. The final $(nm - \ell + r)$ rows of J, corresponding to the transitory shocks in $S\varepsilon_t$, are zero as they have no permanent component. As shown by Pagan and Pesaran (2009), for the shocks to the $I(1)$ elements S_1Y_t to be permanent requires that $\alpha_1 = 0$ in

$$\alpha_0 = \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix},$$

where α_1 is the $(\ell - r) \times r$ submatrix containing the error-correction corresponding to the variables of Y_t (namely the first $\ell - r$ elements of SY_t) that experience permanent shocks. Therefore, cointegration modelling should impose this restriction, by excluding error-correction terms in the equations for the $I(1)$ variables that are the source(s) of the permanent shocks to the system. This implies that the adjustment to the longrun cointegrating relationship(s) is achieved by the remaining $I(1)$ variables, namely the elements of S_2Y_t.

One final point concerns the computation of impulse responses. The common trends representation (8) can be used to obtain the autoregressive-moving average form for Y_t as

$$G(L)\,Y_t = J^*(L)\,\varepsilon_t, \tag{10}$$

[4] To transform the stationary variables to a SVECM form note that any levels variable can be transformed into a sequence of differenced variables and a levels effect, for convenience the levels effect is found at the first lag. For example, a dynamic specification of the $I(0)$ variable $Z_t = \alpha_1 Z_{t-1} + \alpha_2 Z_{t-2} + \alpha_3 Z_{t-3} + \nu_t$, can be rewritten equivalently as $\Delta Z_t = (\alpha_1 + \alpha_2 + \alpha_3 - 1)\,Z_{t-1} - (\alpha_2 + \alpha_3)\,\Delta Z_{t-1} - \alpha_3 \Delta Z_{t-2} + \nu_t$.

where $G(L)$ is the same matrix as in (1) and $J^*(L)$ cumulates the permanent shocks of Je_t, as well as reflecting transitory shocks to the remaining variables. Impulse response functions can be computed in the usual way through (10).

3 Empirical Specification

Having considered the econometric issues, we now detail how the specification can be applied for modelling the interactions between the US and the Euro Area. For each economy, the basic framework is an IS curve, a Phillips curve and a monetary policy reaction function. However, these allow for cross-country influences (as appropriate), with the model closed by a real bilateral exchange rate equation. This is implemented as an SVECM specification as in (5), with restrictions imposed to yield lower triangular B_0 (after any required predominance re-ordering), with these restrictions reflecting predominance assumptions, in addition those inherent in the order adopted for the variable blocks within Y_t.

In line with Section 2, we discuss first the predominance issues, in addition to contemporaneous relationships more generally, before considering the implications of cointegration modelling. Other details of the specification can be found in Appendix 1.

3.1 Contemporaneous Relationships and Predominance

Following the proposal in Section 2 of using an ordering by variable type, the observation vector for the VAR is specified as $Y_t = (y_t', \pi_t', r_t', q_t)'$. Each of the first three subvectors of Y_t (capturing output, inflation and short-term interest rates) are 2×1 and contain observations on each of the two economies, US and EA (that is $m = 2$) while the final subvector contains the single variable q_t, which is the real bilateral exchange rate between the US dollar and the euro. Hence, in detail, $Y_t = (y_t^{US},\, y_t^{EA},\, \pi_t^{US},\, \pi_t^{EA},\, r_t^{US},\, r_t^{EA},\, q_t)'$, where the output variables and the real exchange rate are expressed as logarithms.

The ordering of the variable blocks within Y_t conforms with the implications of macroeconomic theory, and allows output to respond to past shocks, with inflation then responding to demand pressures and the monetary policy authorities setting interest rates in the light of both these variables. Finally, the foreign exchange market reacts to developments in all other variables. The contemporaneous relationships between the variables is given by

$$B_0 D\, \Delta Y_t = \begin{bmatrix} B_{11}^0 & 0 & 0 & 0 \\ B_{21}^0 & B_{22}^0 & 0 & 0 \\ B_{31}^0 & B_{32}^0 & B_{33}^0 & 0 \\ B_{41}^0 & B_{44}^0 & B_{43}^0 & 1 \end{bmatrix} \begin{bmatrix} D_1 \Delta y_t \\ D_2 \Delta \pi_t \\ D_3 \Delta r_t \\ D_4 \Delta q_t \end{bmatrix}. \tag{11}$$

Reflecting the causal ordering of the variable blocks, B_0 has a lower block triangular form. The final row block (representing the real exchange rate) is a row vector, and the corresponding B_{4j}^0 $(j = 1, 2, 3)$ are unrestricted. Also, since there is only one exchange rate series between the two economies, predominance reordering is not relevant and $D_4 = 1$.

The penultimate row block of B_0 represents a standard monetary policy reaction function, where interest rates are determined in relation to domestic economic conditions. With monetary policy conducted independently in each economy, no predominance assumption is required and hence $D_3 = I_2$ with $B_{33}^0 = I_2$. Further, this standard assumption for the conduct of monetary policy implies that B_{31}^0 and B_{32}^0 are diagonal matrices, since there is no direct influence of foreign output or inflation on domestic interest rate setting.

The first two row blocks of B_0 capture contemporaneous relationships for output and inflation. Consistent with an open economy IS curve, the relationship between domestic output and foreign inflation is restricted to be zero. However, the block B_{21}^0 is unrestricted, hence allowing an influence for foreign output on inflation - representing the transmission mechanism for inflation shocks suggested in Woodford (2007). Further, direct links are presumed to exist between both inflation and output in the two economies and we implement predominance arguments to achieve identification.

Since $m = 2$ in both the first and second blocks of B_0, only two orders are possible and the predominance ordering matrices D_1 and D_2 may be either identity matrices or matrices of the form of (3), in order to achieve lower diagonal

B_{11}^0 and B_{22}^0. Four cases can be considered and will be examined in what follows: (I) the US is predominant in output and inflation; (II) the EA is predominant in inflation and the US predominant in output; (III) the EA is predominant in inflation and output; (IV) the US is predominant in output and the EA is predominant in inflation.

The four cases just outlined represent different assumptions about the sources of the output and inflation shocks in these two countries. There is empirical evidence that US output is less affected by external factors than Euro Area countries (see, for example, Kose, Otrok and Whiteman, 2008, or Perez, Osborn and Artis, 2006), which suggests that US predominance may be plausible for output. However, in common with Bayoumi and Swiston (2009), we do not take a strong stand on the appropriate assumption for the source of output shocks in this international context. Indeed, despite substantial recent evidence that international inflation linkages are strong (see, for example, Ciccarelli and Mojon, 2008, or Monacelli and Sala, 2009), the appropriate predominance assumption for inflation is even less clear. Although US predominance over the Euro Area is supported by the results in Galesi and Lombardi (2009), the differences they report are not large.

The specification we employ for the lag matrices B_i $(i = 1, ..., p-1)$ of the SVECM model (5) is detailed in Appendix 1.

3.2 Cointegration

Our system contains $\ell = 3$ variables that are $I(1)$, namely y_t^{US}, y_t^{EA} and q_t, with this classification supported by conventional unit root tests. Although the order of integration of inflation and nominal interest rates is sometimes debated, our specification assumes the elements of π_t and r_t are stationary, 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.

Testing reveals a single cointegrating vector between the non-stationary variables, which can be interpreted as an international IS curve (see Appendix 2). Hence $r = 1$ and the non-stationary variables are driven by $\ell - r = 2$ permanent shocks. These permanent shocks are assumed to originate in the output variables, y_t^{US} and y_t^{EA}, representing two distinct technology shocks. While theoretical international models typically assume common cross-economy technology shocks, 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 explanator 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.

In the notation of Section 2, these considerations point to the re-ordering for the purposes of cointegration analysis as:

$$SDY_t = \begin{bmatrix} I_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & I_2 & 0 & 0 \\ 0 & 0 & I_2 & 0 \end{bmatrix} \begin{bmatrix} D_1 y_t \\ D_2 \pi_t \\ r_t \\ q_t \end{bmatrix} \tag{12}$$

where all matrices in all row blocks except the second are 2×2; the zero matrices in the second row block are 2×1 row vectors, while the final element of this row is scalar. Note that the predominance order matrices D_1 and D_2 enter (12), which enables us to consider the four predominance cases indicated in the previous subsection. Further, the predominance embodied in D_1 orders the permanent shocks, so that attributed to the second country (after any re-ordering) is obtained conditional on the first shock. In other words, although distinct (permanent) output shocks impact on the two economies, the disturbances in v_{1t}, in notation of (1), may be correlated.

As discussion in Section 2, the error-correction coefficients for the variables in $S_1 Y_t$ should be set to zero, since these shocks are permanent (Pagan and Pesaran, 2009). Consequently, the restriction $\alpha_1 = 0$ is imposed in our specification, so that no error-correction applies to the elements of $y_t = (y_t^{US}, y_t^{EA})'$.

A further issue arises in relation to transitory output "gap" variables, defined as $y_t - y_t^P$, where y_t^P is the 2×1 non-stationary vector containing the permanent components of y_t, as given by (9). As widely recognised in macro modelling, it is these output gap variables, rather than Δy_t, that are relevant in the equations for inflation and interest rates. To our knowledge, however, 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. Nevertheless, their focus is on a single equation and they use a previously computed output gap series. In our system context we follow Dungey and Pagan (2009) and approximate the output gap effects in the inflation and monetary policy equations by supplementing Δy_t^{US} and/or Δy_t^{EA} by also including the error-correction term in these equations.

4 Empirical Results:Baseline Model Responses

The data used for our empirical application to the US and the Euro Area are described in Appendix 2, which also includes graphs of the series. Quarterly data are employed, with the sample period of 1983Q1 to 2007Q4 represents the period of the move towards, and establishment of, a common currency in Europe and following the Volker experiment period in the US[5]. This sample period also avoids any unusual relationships that may have applied during the recent world recession. All results reported are obtained from VAR specifications using 3 lags in the levels of all variables, corresponding to two lags in the difference VECM notation of (5). Appendix 2 provides further details, including the estimated cointegrating relationship between the (logged) values y_t^{US}, y_t^{EA} and q_t.

The remainder of this section discusses the impulse responses obtained from a baseline specification which assumes US predominance for both output and inflation. This provides the backdrop to the subsequent comparison in the following section of the four predominance scenarios relating to output and inflation discussed in Section 3.

[5] The European Monetary System was established in March 1979, while the Volker experiment of targeting extended from 1979 to 1982. The choice of starting date is also influenced by Halunga, Osborn and Sensier (2009), who conclude that US inflation changed from $I(1)$ to $I(0)$ in 1982.

Responses of the baseline model, where $D_1 = D_2 = I_2$ in (12), to domestic shocks discussed first and cross-economy responses in subsection 4.2. All shocks are set equal to one standard error, the sizes of which are presented in Table 1. The smaller magnitude of Euro Area inflation shocks is due to the assumption of US inflation predominance, and hence the conditioning of these shocks on US inflation[6]. 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[7].

4.1 Domestic Responses

Figure 1(a and b) shows the results for the (permanent) shocks to output in each economy. Key monetary policy effects of inflation shocks on interest rates and interest rate shocks on domestic inflation for are shown for the US and the Euro Area in Figure 1(c to f). A number of features are evident. First, in panels (c and d), a domestic inflation shock in either economy causes a strong monetary policy response, with interest rates in each economy increasing significantly. Second, in panels (e and f) monetary policy shocks in the form of interest rate shocks lead to initial falls in domestic inflation in both economies. In the US there is some evidence of a price puzzle in the second quarter response, but this reverts to a negative effect the quarter afterwards and subsequently becomes significant 3.5 years after the shock[8]. In the Euro Area, the response is relatively short, remaining negative for some 18 months after the shock, but remaining statistically insignificant throughout.

[6] We thank David Fielding for discussions on this point. The need for including direct cross economy inflation links was supported by earlier versions of the paper, where without such a structure the residual covariance between the two inflation shocks was 0.65, see the CAMA working paper 24/2009 titled "Modelling International Linkages for Large Open Economies: US and Euro Area".

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

[8] This price puzzle effect is removed if foreign output is dropped from the Phillips curve.

4.2 Cross-Economy Responses

Figure 2 shows 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 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 substantial delay for interest rates.

US monetary policy shocks cause a marginally significant rise in Euro Area output, due to the associated depreciation 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 predominance assumptions we make for US output and inflation. Nevertheless, and as implied by the results discussed in subsection 4.1, 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 1 that the output shocks are similar in these two cases).

The two economies have asymmetric responses to inflation shocks sourced internationally. While higher US inflation leads 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, 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). In this case the associated depreciation of the US dollar does not stimulate net exports to the Euro Area sufficiently to overcome 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).

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.

5 Predominance Assumption Experiments

In comparison with the benchmark case just discussed, this subsection considers three alternative predominance assumptions, retaining the structure of the model to be otherwise the same as the benchmark. The four experiments are therefore (I) the benchmark model where the US economy is predominant in both output and inflation ($D_1 = D_2 = I_2$); (II) the US economy is predominant in output, and the Euro Area is predominant in inflation ($D_1 = I_2$ and D_2 as (3); (III) the Euro Area is predominant in both output and inflation ($D_1 = D_2$, as defined in (3); and (IV) the Euro Area is predominant in output and the US economy is predominant in inflation (D_1 having the form of (3) and $D_2 = I_2$. Where there are differences in the results two important pairing patterns provide interpretation: inflation predominance matters when the results for experiments I and IV (II and III) are similar but differ from those for experiments II and III (I and IV), and output predominance matters when the results for experiments I and II (III and IV) pair but differ from the results for experiments III and IV (I and II). For comparability, a given shock has the magnitude given in Table 1 across all four experiments conducted for the effects of that shock.

Results are presented in Tables 2 to 4 as point estimates of the impulse responses after 2, 4 and 12 quarters (left-hand panels), together with the cumulated responses for these horizons (right-hand panel), together with one standard error confidence bands. References to statistical significance are made in relation to these bands. The majority of the responses of the model are only marginally affected by the change in predominance assumptions, and hence only results are shown where the effects differ substantively or where they are of particular interest. In particular, all effects of exchange rate shocks are very similar and hence are not shown.

Table 2 shows, in the first two (horizontal) panels, the impact of shocks to the interest rate in one economy on the interest rate in the other. Notice that the results are very similar across the four experiments, and hence are effectively invariant to the predominance assumptions made. However, there are differences across the two economies. The conclusion that the US interest rate shock has a statistically significant positive cumulative effect on Euro Area interest rates at the three year horizon, while a Euro Area interest rate shock has no significant cumulative effect on US interest rates, is robust across the experiments.

The responses of domestic interest rates to domestic inflation shocks, in the lower half of Table 2, also do not differ markedly across the experiments. This evidence supports the argument that monetary policy responses reflect domestic rather than international conditions - consequently the change in international (output and inflation) transmissions across the experiments does not have undue influence on domestic policy response to domestically sourced inflation shocks.

Table 3 presents the effects of inflation shocks on inflation and interest rates in the other economy. These depend on the inflation predominance assumed: the results for experiments I and IV (II and III) are very similar, but differ substantially from those reported for experiments II and III (I and IV). In the case of inflation shocks, the 3 year cumulated effects of a US (Euro Area) inflation shock on Euro Area (US) inflation when US (Euro Area) inflation is predominant is around 3 times larger than when the Euro Area (US) inflation is predominant. There is also evidence that these effects differ significantly, in that the point estimates for some experiments fall outside the confidence bands for other experiments under the same shock, with this especially evident comparing I and IV to II and III for the cumulated responses at the three year horizon.

The effects of inflation shocks in one economy on interest rates in the other economy in Table 3 represent domestic monetary policy reactions to foreign inflation shocks. In this case there are noticeable differences between the responses across the experiments, once again based on the inflation predominance assumption used: a US (Euro Area) inflation shock has a larger impact on Euro Area (US) interest rates under US (Euro Area) inflation predominance. That is, when the inflation predominance assumption matches the source of the foreign inflation shock, the impact on domestic interest rates is larger.

Table 4 presents the results of monetary policy shocks as represented by interest rate shocks for each economy on their own inflation and output. We have already seen, in Tables 2 and 3, that interest rate responses to domestically sourced inflationary shocks do not change markedly over the different experiments, while interest rate responses to foreign sourced inflationary shocks depend on the inflation predominance assumption. In the case of monetary policy shocks, the inflation responses to interest rate shocks do not display any simple pattern across the different experiments, and are all statistically insignificant. For example, a Euro Area interest rate shock on Euro Area inflation in the case of Euro Area inflation predominance has a 2 quarter point estimate double that for the same shock under US inflation predominance. However, the cumulated shocks over 12 quarters show no discernible difference. In the case of the responses of output to own economy interest rate shocks, there is some slight evidence that the output predominance assumption affects the results. Where US (Euro Area) output predominance is assumed the effect of US (Euro Area) monetary policy shocks on US (Euro Area) output is smaller, but none of these effects are statistically significant.

In summary, the results show that while many results are robust to the predominance assumptions, the inflation predominance assumption has more discernible impact on the results than the output predominance assumption.

Indeed, the cross-economy effects of foreign inflation shocks on domestic inflation and (hence) on domestic monetary policy responses depend crucially on this assumption. In this way our results expand those of Bayoumi and Swiston (2009) who examine only output predominance. In particular, the analysis of monetary policy effects under different predominance assumptions demonstrate that the transmission mechanism for international shocks has an impact on the point estimates, albeit usually insignificant. In particular, the predominance assumption for output marginally effects the impact of monetary policy shocks on domestic output, and the predominance assumption for inflation effects the impact of monetary policy shocks on domestic inflation. In this case the source of inflationary shocks is important, only in the case of foreign sourced inflationary shocks does the inflation predominance assumption affect the domestic monetary policy response.

6 Conclusion

Modellling the interactions between large open economies in an empirically coherent way provides significant challenges, but is extraordinarily important for policy formation. This paper goes some way to modelling linkages between open economies in a structural VAR framework, without necessarily imposing a strict exogeneity ordering between two economies. We recognise that one way to achieve identification is to restrict the contemporaneous relationships between some international variables, while both dynamic relationships and long run cointegrating relationships can provide bidirectional feedback between economies. A major innovation of the paper is the introduction of variable ordering, where by rather than ordering variables in a country by country manner, as typically done in multicountry VAR studies, we group like data series together across different countries. In this we are able to retain within country economic structure typically seen in VAR models (for example output, inflation and interest rates in that order) but have potentially different structures in the contemporaneous relationships across economies. The restrictions across international relationships between contemporaneous variables are denoted predominance assumptions. These are related to the dominance assumptions of Pesaran and Chudik (2010) who refer to a dominant unit in anchoring VAR specifications as the number of countries increases. Predominance assumptions may vary within the model across different blocks of variables - so that the predominance of country A in one set of international relationships may be replaced by the predominance of country B in another set. There is no requirement that one economy is always dominant, which is a major advantage of our approach.

The application to the US and the Euro Area brings out the relative importance of these predominance assumptions. The assumption of US output predominance in preference to Euro Area output predominance makes little difference to the results. However, while the source of inflation predominance makes little difference to either economy's reaction to domestically sourced inflation shocks, monetary policy responses to foreign sourced inflation shocks are affected. When the predominance assumption matches the source of the foreign inflation shock, the domestic monetary policy response is more pronounced.

The framework can be extended to incorporate a greater number of economies. In such a case, it may be natural to assume that larger economies (say the US and the Euro Area) are both predominant over smaller economies (such as Canada or the Accession countries of the European Union), and hence the number of predominance assumptions required will not necessarily grow exponentially with the number of ountries considered. Developing the approach in this way is, however, a matter for future work.

References

[1] Anderson, H., Dungey, M., Osborn, D.R., and Vahid, F. (2008) "Financial Integration and the Construction of Historical Data for the Euro Area", manuscript.

[2] Assenmacher-Wesche, K. and Pesaran, H. (2009), "A VECX* model of the Swiss Economy", *Economic Studies, Swiss National Bank*, Number 6.

[3] Bataa, E., Osborn, D.R., Sensier, M. and van Dijk, D. (2009), "Structural Breaks in the International Transmission of Inflation", Centre for Growth and Business Cycle Research, Discussion Paper 119, University of Manchester.

[4] Bayoumi, T. and Swiston, A. (2009), "Foreign Entanglements: Estimating the Source and Size of Spillovers Across Industrial Countries, *IMF Staff Papers*, 56, 353-383.

[5] Canova, F. and Ciccarelli, M. (2009), "Estimating Multicountry VAR models", *International Economic Review*, 50, 929-959.

[6] Catão, L., Laxton, D. and Pagan, A. (2008), "Monetary Transmission in an EmergingTargeter: The Case of Brazil", *IMF Working Paper*, 08/191.

[7] Ciccerelli, M. and Mojon, B. (2008), "Global Inflation", *Review of Economics and Statistics*, forthcoming (Federal Reserve Bank of Chicago, working paper 2008-05).

[8] Cushman, D. O., and Zha, T. (1997) "Identifying monetary policy in a small open economy under flexible exchange rates", *Journal of Monetary Economics*, 39, 433–44

[9] Dees, S., di Mauro, F, Pesaran, H. and Smith, V. (2007). "Exploring the international linkages of the euro area: a global VAR analysis," *Journal of Applied Econometrics*, 22, 1-38.

[10] Dees, S., Pesaran, M.H., Smith, L.V. and Smith, R.P. (2009), "Identification of new Keynesian Phillips Curves from a Global Perspective", *Journal of Money, Credit and Banking*, 41, 1481-1502.

[11] Dungey, M. and Fry, R. (2008) "The Identification of Fiscal and Monetary Policy in a Structural VAR", *Economic Modeling,* 26, 1147-1160.

[12] Dungey, M. and Pagan, A.R. (2009) "Extending an SVAR Model of the Australian Economy", *Economic Record*, 85,1-20.

[13] Fagan, G., Henry, J. and Mestre, R. (2005) "An Area Wide Model (AWM) for the Euro Area", *Economic Modeling*, 22, 39-59.

[14] Galesi, A. and Lombardi, M.J. (2009), "External Shocks and International Inflation Linkages", European Central Bank, Working Paper 1062.

[15] Gali, J. and Monacelli, T. (2005) "Monetary Policy and Exchange Rate Volatility in a Small Open Economy", *Review of Economic Studies*, 72, 707-734.

[16] Kose, M.A., Otrok, C. and Whiteman, C.H. (2008) "Understanding the Evolution of World Business Cycles", *Journal of International Economics*, 75, 110-130.

[17] Mellander, E., Vredin A. and Warne A. (1992), "Stochastic Trends and Economic Fluctuations in a Small Open Economy", *Journal of Applied Econometrics*, 7, 369-394.

[18] Monacelli, T. (2005) "Monetary Policy in a Low Pass-Through Environment", *Journal of Money, Credit and Banking*, 37, 1048-1066.

[19] Monacelli, T. and Sala, L. (2009), "The International Dimension of Inflation: Evidence from Disaggregated Consumer Price Data", *Journal of Money, Credit and Banking,* 41, 101-120.

[20] Orlowski, L.T. (2005), "Monetary Convergence of the EU Accession Countries to the Eurozone: A Theoretical Framework and Policy Implications", *Journal of Banking and Finance*, 29, 203-225.

[21] Pagan, A.R. and Pesaran, M.H. (2009) "On Econometric Analysis of Structural Systems with Permanent and Transitory Shocks and Exogenous Variables", *Economic Dynamics and Control*, 32, 3376-3395.

[22] Perez, P.J., Osborn, D.R., and Artis, M. (2006) "The International Business Cycle in a Changing World: Volatility and the Propagation of Shocks in the G-7", *Open Economies Review*, 17, 255-279.

[23] Pesaran, M.H. and Chudik, A. (2010) "Econometric Analysis of High Dimensional VARs Featuring a Dominant Unit", European Central Bank, Working Paper No 1194.

[24] Pesaran, H., Smith, R. and Smith, V.L. (2007) "What if the UK or Sweden had joined the Euro In 1999? An Empirical Evaluation Using A Global VAR", *International Journal of Finance and Economics*,12, 55-87

[25] Smets, F. and Wouters, R. (2003), "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area", *Journal of the Economics Association*, 1, 1123-1175.

[26] Smets, F. and Wouters, R. (2005) "Comparing Shocks and Frictions in US and Euro Area Business Cycles: a Bayesian DSGE Approach", *Journal Applied Econometrics*, 20, 161-183.

[27] Woodford. M. (2007), "Globalization and Monetary Control", NBER Working Paper 13329.Uhlig, H. (2009) "Monetary Policy in Europe vs the US: What Explains the Difference?", NBER Working Paper, 14996.

[28] van Aarle, B., Garretson, H. and Gobbin, N. (2003) "Monetary and Fiscal Policy Transmission in the Euro Area: evidence from a structural VAR analysis", *Journal of Economics and Business*, 55, 609-638.

Table 1: 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%

Table 2: Impulse Responses for Dominance Experiments: Interest Rate Responses to Interest Rate and Inflation Shocks

horizon	**point estimates**				**cumulated response**			
quarters	expt 1	expt 2	expt 3	expt 4	expt1	expt2	expt3	expt4
				US interest rate shock on EA interest rate %p.a.				
2	0.003	0.003	0.004	0.004	0.003	0.003	0.004	0.004
	[0.000,0.007]	[-0.001,0.007]	[0.000,0.008]	[0.000,0.007]	[0.000,0.007]	[-0.001,0.007]	[0.000,0.008]	[0.000,0.007]
4	0.012	0.014	0.016	0.014	0.024	0.026	0.030	0.027
	[-0.003,0.028]	[-0.003,0.030]	[0.000,0.032]	[-0.001,0.030]	[-0.003,0.052]	[-0.003,0.055]	[0.001,0.058]	[0.001,0.054]
12	0.101	0.019	0.019	0.099	0.551	0.598	0.622	0.567
	[0.032,0.170]	[0.070,0.162]	[0.071,0.159]	[0.005,0.073]	[0.099,1.003]	[0.124,1.063]	[0.158,1.068]	[0.137,0.999]
				EA interest rate shock on US interest rate %p.a.				
2	0.001	0.001	-0.002	-0.002	0.001	0.001	-0.002	-0.002
	[-0.002,0.003]	[-0.001,0.004]	[0.000,0.007]	[0.000,0.006]	[-0.002,0.003]	[-0.001,0.004]	[-0.002,0.007]	[0.000,0.006]
4	-0.013	-0.001	-0.014	-0.017	-0.019	0.012	-0.026	-0.031
	[-0.025,-0.002]	[-0.022,0.001]	[-0.016,0.010]	[-0.018,0.006]	[-0.039,0.002]	[-0.034,0.008]	[-0.023,0.027]	[-0.027,0.020]
12	-0.021	-0.017	-0.016	-0.019	-0.058	-0.044	-0.059	-0.070
	[-0.060,0.039]	[-0.053,0.030]	[-0.038,0.030]	[-0.042,0.039]	[-0.482,0.173]	[-0.413,0.152]	[-0.295,0.188]	[-0.335,0.206]
				US inflation shock on US interest rate %p.a.				
2	0.108	0.101	0.102	0.109	0.157	0.149	0.150	0.157
	[0.054,0.161]	[0.052,0.150]	[0.053,0.152]	[0.056,0.163]	[0.069,0.244]	[0.066,0.233]	[0.068,0.234]	[0.071,0.246]
4	0.190	0.168	0.171	0.189	0.488	0.440	0.447	0.488
	[0.101,0.279]	[0.090,0.244]	[0.093,0.246]	[0.109,0.285]	[0.232,0.741]	[0.208,0.669]	[0.214,0.675]	[0.248,0.754]
12	0.001	0.001	0.001	0.001	2.617	2.159	2.063	2.468
	[0.141,0.310]	[0.088,0.230]	[0.082,0.224]	[0.140,0.306]	[1.750,3.594]	[1.416,2.966]	[1.387,2.937]	[1.784,3.622]
				EA inflation shock on EA interest rate %p.a.				
2	0.081	0.085	0.084	0.080	0.144	0.148	0.147	0.143
	[0.044,0.120]	[0.046,0.123]	[0.046,0.123]	[0.043,0.119]	[0.084,0.206]	[0.086,0.210]	[0.098,0.438]	[0.083,0.408]
4	0.051	0.061	0.061	0.049	0.250	0.270	0.268	0.246
	[-0.004,0.104]	[0.002,0.119]	[0.002,0.118]	[-0.006,0.101]	[0.087,0.413]	[0.100,0.440]	[0.098,0.438]	[0.083,0.408]
12	0.036	0.088	0.089	0.036	0.675	0.951	0.961	0.670
	[0.006,0.070]	[0.051,0.129]	[0.053,0.128]	[0.007,0.068]	[0.156,0.188]	[0.352,1.557]	[0.371,1.553]	[0.161,1.177]

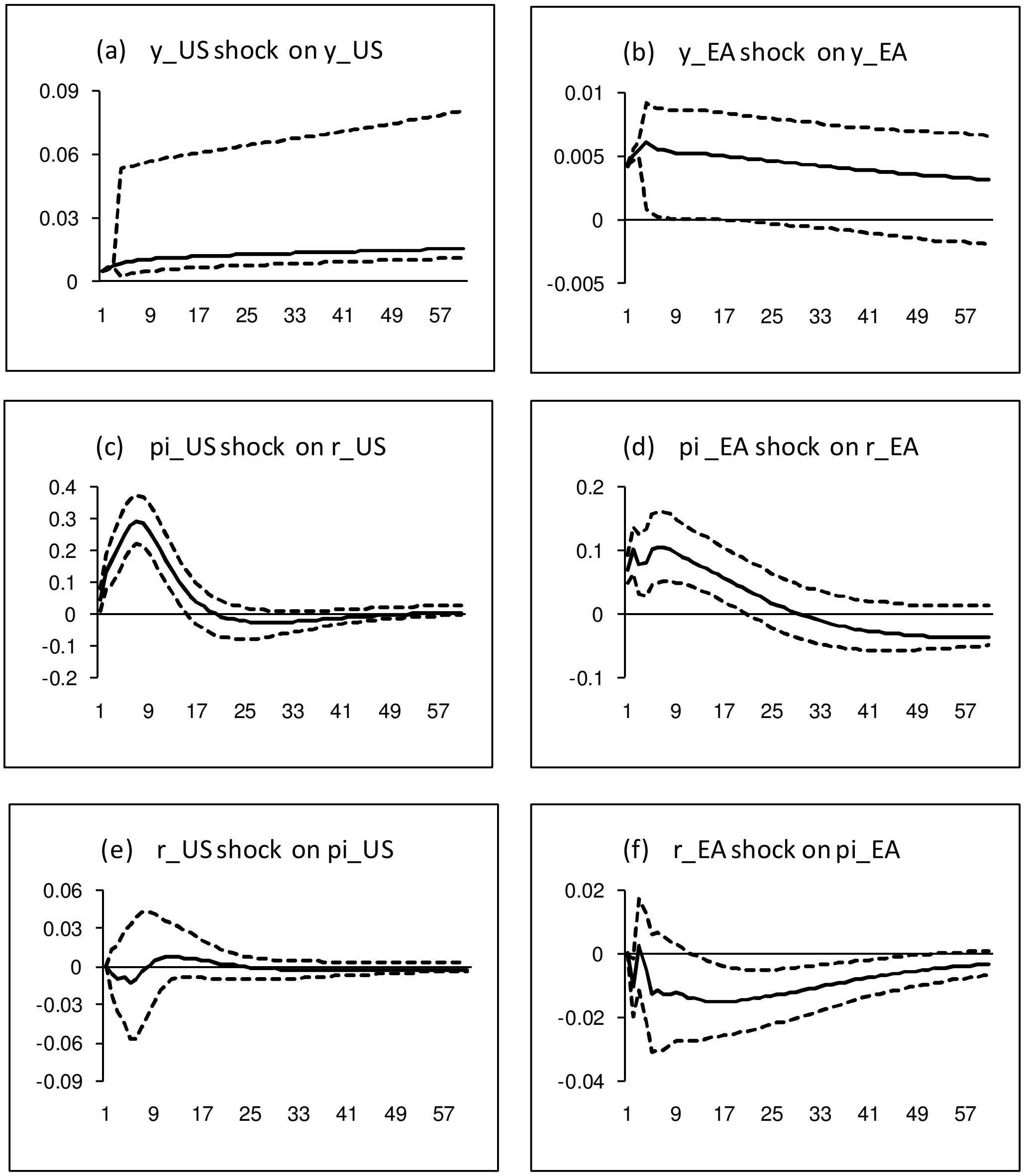
Table 3: Impulse Responses for Dominance Experiments: Cross Economy Inflation and Interest Rate Responses to Inflation Shocks

horizon	**point estimates**				**cumulated impulses**			
quarters	expt 1	expt 2	expt 3	expt 4	expt1	expt2	expt3	expt4
				US inflation shock on EA inflation %p.a.				
2	0.840	0.082	0.083	0.839	1.646	0.082	0.083	1.645
	[0.693,0.981]	[-0.068,0.234]	[-0.068,0.236]	[0.692,0.978]	[1.406,1.876]	[-0.068,0.234]	[-0.068,0.236]	[1.406,1.874]
4	0.897	0.258	0.260	0.399	3.387	0.510	0.516	3.390
	[0.716,1.111]	[0.096,0.436]	[0.098,0.438]	[0.720,1.113]	[2.773,4.043]	[-0.001,1.046]	[0.003,1.053]	[2.776,4.041]
12	0.718	0.360	0.269	0.707	10.237	3.436	3.454	10.231
	[0.596,0.860]	[0.237,0.479]	[0.237,0.477]	[0.596,0.862]	[8.584,12.354]	[2.014,5.950]	[2.039,4.970]	[8.608,12.374]
				EA inflation shock on US inflation %p.a.				
2	0.305	1.164	1.163	0.306	0.305	2.141	2.140	0.306
	[0.134,0.478]	[0.989,1.337]	[0.986,1.334]	[0.132,1.334]	[0.134,0.478]	[1.856,2.420]	[1.853,2.417]	[0.132,0.477]
4	0.365	0.892	0.894	0.363	1.061	4.113	4.115	1.063
	[0.176,0.592]	[0.667,1.163]	[0.674,1.168]	[0.179,0.594]	[0.475,1.702]	[3.368,4.936]	[3.369,4.933]	[0.476,1.703]
12	0.049	0.123	0.114	0.049	2.294	6.786	6.734	2.252
	[-0.014,0.099]	[0.036,0.184]	[0.031,0.180]	[-0.013,0.099]	[1.110,3.719]	[5.253,8.552]	[5.281,8.581]	[1.160,3.769]
				US inflation shock on EA interest rate %p.a.				
2	0.078	0.005	0.006	0.078	0.134	0.005	0.006	0.134
	[0.042,0.115]	[-0.005,0.016]	[-0.005,0.016]	[0.042,0.114]	[0.077,0.192]	[-0.005,0.016]	[-0.005,0.016]	[0.077,0.192]
4	0.065	0.017	0.020	0.066	0.259	0.033	0.038	0.260
	[0.008,0.123]	[-0.002,0.038]	[0.001,0.040]	[0.009,0.123]	[0.096,0.423]	[-0.014,0.083]	[-0.008,0.087]	[0.098,0.422]
12	0.150	0.098	0.099	0.150	1.221	0.501	0.527	1.240
	[0.087,0.212]	[0.046,0.151]	[0.078,0.151]	[0.091,0.212]	[0.511,1.923]	[0.135,0.867]	[0.170,0.883]	[0.548,1.935]
				EA inflation shock on US interest rate %p.a.				
2	0.007	0.058	0.058	0.007	0.007	0.082	0.082	0.007
	[0.000,0.147]	[0.028,0.087]	[0.030,0.089]	[0.000,0.016]	[0.000,0.015]	[0.035,0.129]	[0.037,0.130]	[0.001,0.016]
4	0.024	0.108	0.104	0.019	0.050	0.271	0.267	0.042
	[0.002,0.046]	[0.055,0.161]	[0.062,0.168]	[0.008,0.053]	[0.006,0.095]	[0.127,0.415]	[0.141,0.428]	[0.016,0.108]
12	0.034	0.112	0.098	0.032	0.323	1.416	1.321	0.276
	[-0.001,0.075]	[0.070,0.162]	[0.071,0.159]	[0.005,0.073]	[0.008,0.682]	[0.892,1.999]	[0.939,2.033]	[0.081,0.725]

Table 4: Selected Impulse Responses for Dominance Experiments: Interest Rate Shocks on Own Economy Inflation and Output

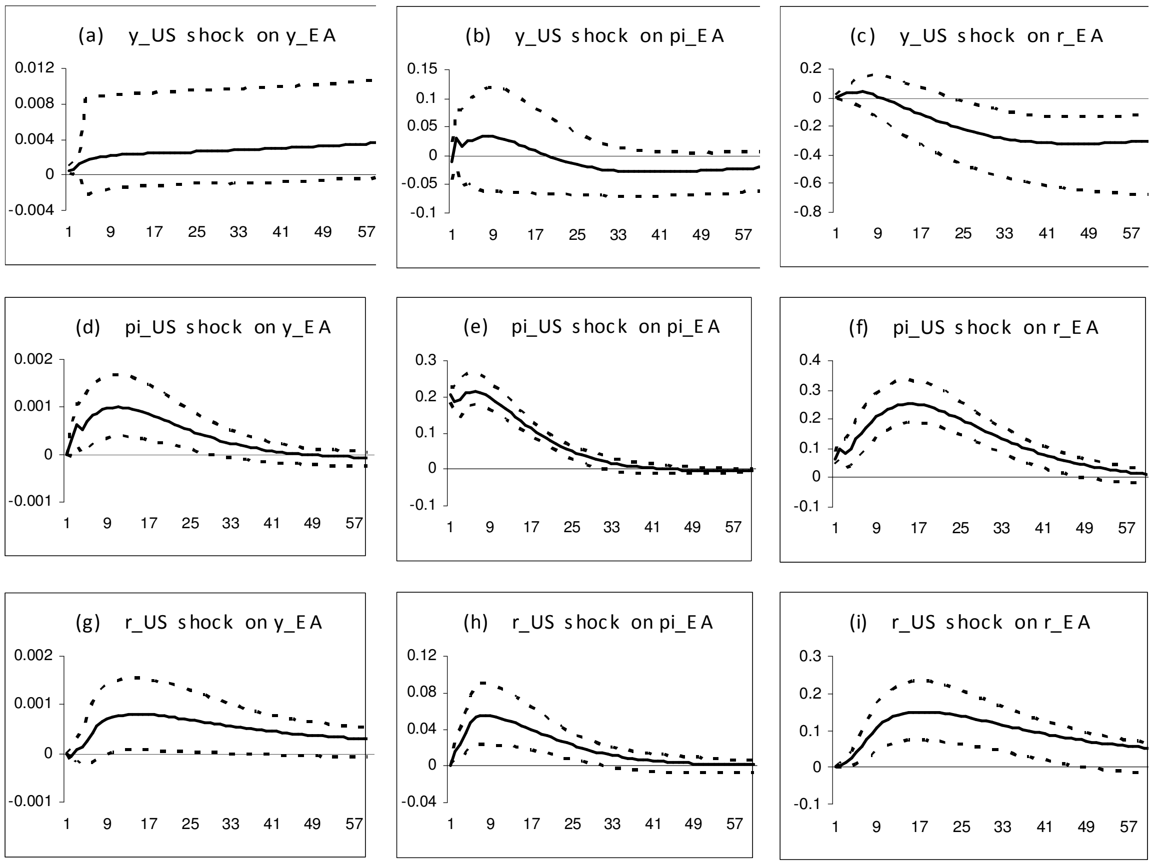
horizon	**point estimates**				**cumulated impulses**			
quarters	expt 1	expt 2	expt 3	expt 4	expt 1	expt 2	expt 3	expt 4
				US interest rate shock on US inflation %p.a.				
2	-0.007	-0.012	-0.011	-0.006	-0.007	-0.012	-0.011	-0.005
	[-0.071,0.056]	[-0.074,0.051]	[-0.074,0.053]	[-0.070,0.058]	[-0.071,0.506]	[-0.074,0.051]	[-0.074,0.053]	[-0.070,0.058]
4	-0.072	-0.053	-0.049	-0.074	-0.139	-0.120	-0.109	-0.135
	[-0.218,0.081]	[-0.196,0.091]	[-0.194,0.091]	[-0.226,0.082]	[-0.449,0.177]	[-0.421,0.181]	[-0.414,0.190]	[-0.455,0.188]
12	-0.016	0.060	0.046	-0.034	-0.662	-0.089	-0.215	-0.855
	[-0.128,0.124]	[-0.034,0.174]	[-0.033,0.172]	[-0.127,0.126]	[-2.316,1.117]	[-1.670,1.524]	[-1.712,1.438]	[-2.433,1.012]
				EA interest rate shock on EA inflation %p.a.				
2	-0.043	-0.022	-0.023	-0.041	-0.043	-0.022	-0.023	-0.041
	[-0.083,-0.005]	[-0.064,0.021]	[-0.064,0.017]	[-0.083,-0.007]	[-0.083,-0.005]	[-0.064,0.021]	[-0.064,0.017]	[-0.083,-0.007]
4	-0.037	-0.016	-0.025	-0.042	-0.101	-0.018	-0.035	-0.105
	[-0.098,0.021]	[-0.094,0.062]	[-0.102,0.051]	[-0.096,0.020]	[-0.257,0.046]	[-0.205,0.170]	[-0.217,0.145]	[-0.253,0.041]
12	-0.042	-0.057	-0.064	-0.044	-0.428	-0.390	-0.483	-0.455
	[-0.101,0.017]	[-0.122,0.015]	[-0.128,0.001]	[-0.106,0.011]	[-1.068,0.201]	[-1.169,0.424]	[-1.230,0.293]	[-1.065,0.173]
				US interest rate shock on US output ($scaled \times 100$)				
2	-0.001	-0.001	0.003	0.003	-0.001	-0.001	-0.003	-0.003
	[-0.044,0.042]	[-0.044,0.042]	[-0.049,0.038]	[-0.049,0.038]	[-0.044,0.042]	[-0.044,0.042]	[-0.049,0.038]	[-0.049,0.038]
4	0.006	0.006	-0.022	-0.022	0.005	0.005	-0.045	-0.045
	[-0.084,0.096]	[-0.083,0.096]	[-0.111,0.073]	[-0.111,0.073]	[-0.193,0.201]	[-0.193,0.201]	[-0.243,0.158]	[-0.244,0.158]
12	0.132	0.129	0.088	0.092	0.682	0.671	0.267	0.286
	[0.016,0.272]	[0.001,0.272]	[0.001,0.268]	[0.001,0.269]	[-0.451,1.812]	[-0.462,1.908]	[-0.655,1.715]	[-0.662,1.716]
				EA interest rate shock on EA output ($scaled \times 100$)				
2	0.100	0.100	0.091	0.091	0.100	0.100	0.091	0.091
	[0.061,0.139]	[0.061,0.139]	[0.052,0.130]	[0.052,0.130]	[0.061,0.139]	[0.061,0.139]	[0.052,0.130]	[0.052,0.130]
4	0.042	0.044	0.025	0.024	0.209	0.212	0.172	0.170
	[-0.028,0.114]	[-0.027,0.117]	[-0.044,0.102]	[-0.045,0.099]	[0.043,0.379]	[0.045,0.383]	[0.005,0.595]	[0.003,0.343]
12	-0.009	-0.010	-0.019	-0.018	0.231	0.236	0.076	0.075
	[-0.063,0.057]	[-0.065,0.057]	[-0.075,0.047]	[-0.071,0.046]	[-0.481,1.035]	[-0.496,1.060]	[-0.642,0.896]	[-0.618,0.879]

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



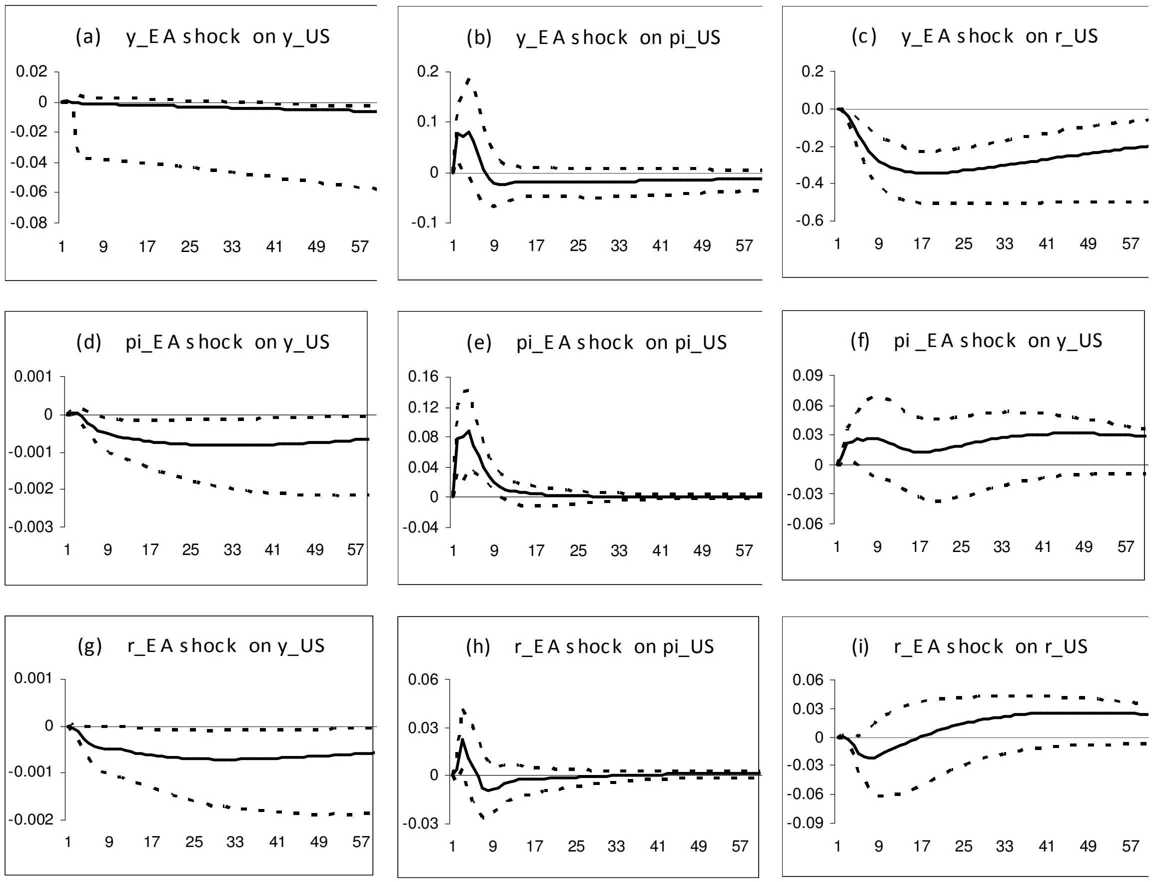
Notes: Impulse responses are shown as unbroken black lines, with their one standard error bands (obtained from 5000 bootstrap replications) indicated by dashed black lines.

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



Notes: See Figure 1.

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



Notes: See Figure 1.

1 Appendix 1: Lag Specification Details

Although the specification of the matrices of dynamic coefficients in (5) reflects that employed for B_0, shown in (11), the lag matrices B_i $(i = 1, ..., p-1)$ incorporate additional feedback effects. Incorporating the dominance assumptions, write the left-hand side of (5) as

$$B(L)D\,\Delta Y_t = \begin{bmatrix} B_{11} & B_{12} & B_{13} & B_{14} \\ B_{21} & B_{22} & B_{23} & B_{24} \\ B_{31} & B_{32} & B_{33} & B_{34} \\ B_{41} & B_{44} & B_{43} & b_{44} \end{bmatrix} \begin{bmatrix} D_1 \Delta y_t \\ D_2 \Delta \pi_t \\ \Delta r_t \\ \Delta q_t \end{bmatrix} \tag{13}$$

where the B_{ij} $(i, j = 1, 2, 3, 4)$ are matrices in the lag polynomial (except for the scalar polynomial b_{44}), whose leading coefficients have the form indicated in (11).

Our specificatiion maintains the domestic determination of the monetary policy reaction function in each country, hence B_{33} is diagonal, while B_{31} and B_{32} are specified in line with D_1 and D_2, respectively. Thus, if $D_1 = D_2 = I_2$, then B_{31} and B_{32} are diagonal, while if D_1 or D_2 represents a re-ordering, then the corresponding B_{31} and/or B_{32} has zero diagonal elements and non-zero off-diagonal ones. Similarly, the elements of B_{12}, B_{13} and B_{23} are specified so that these matrices refer to domestic inflation or interest rates, as appropriate.

Using superscript L to indicate that the matrices refer to lagged (rather than contemporaneous) values, and assuming $D_1 = D_2 = I_2$ for simplicity, the form of $B(L)$ is given by:

$$\begin{bmatrix} b_{11}^{(1,1)} & b_{11}^{(2,1)} & b_{12}^{(1,1)} & 0 & b_{13}^{(1,1)} & 0 & b_{14}^{(1)} \\ b_{11}^{(2,1)} & b_{11}^{(2,2)} & 0 & b_{12}^{(2,2)} & 0 & b_{13}^{(2,2)} & b_{14}^{(1)} \\ b_{21}^{(1,1)} & b_{21}^{(2,1)} & b_{22}^{(1,1)} & b_{22}^{(1,2)} & b_{23}^{(1,1)} & 0 & b_{24}^{(1)} \\ b_{21}^{(2,1)} & b_{21}^{(2,2)} & b_{22}^{(2,1)} & b_{22}^{(2,2)} & 0 & b_{23}^{(2,2)} & b_{24}^{(2)} \\ b_{31}^{(1,1)} & 0 & b_{32}^{(1,1)} & 0 & b_{33}^{(1,1)} & 0 & b_{34}^{(1)} \\ 0 & b_{31}^{(2,2)} & 0 & b_{32}^{(1,1)} & 0 & b_{33}^{(2,2)} & b_{34}^{(2)} \\ b_{41}^{(1)} & b_{41}^{(2)} & b_{42}^{(1)} & b_{42}^{(2)} & b_{43}^{(1)} & b_{43}^{(2)} & b_{44} \end{bmatrix} \begin{matrix} \left.\begin{matrix} \Delta y_t^{US} \\ \Delta y_t^{EA} \end{matrix}\right\} \; y \text{ block} \\ \left.\begin{matrix} \pi_t^{US} \\ \pi_t^{EA} \end{matrix}\right\} \; \pi \text{ block} \\ \left.\begin{matrix} r_t^{US} \\ r_t^{EA} \end{matrix}\right\} \; r \text{ block} \\ \Delta q \text{ block} \end{matrix}$$

in which $b_{k\ell}^{(i,j)}$ indicates the $(i, j)^{th}$ element of $B_{k\ell}$ in (13). All non-zero elements are polynomials of order $p-1$ in the lag operator, with leading coefficients as in (11). For other dominance assumptions, the definitions are changed such that the the zero elements of B_{12}, B_{13}, B_{23}, B_{31}, B_{32}, B_{33} relate to the foreign country.

The restrictions imposed on the lag matrices in $B(L)$ imply that the short-run IS curve is influenced by foreign output, together with domestic real interest rates (captured by interest rates and inflation). With the exchange rate included to allow for incomplete pass-through (Monacelli, 2005), the form of these equations is analogous to that of Carabenciov *et al.* (2008).

In line recent theoretical and empirical analyzes of globalization (including Borio and Filardo, 2007, Ihlig *et al.*, 2007, and Woodford, 2007), the Phillips curve equations include the foreign output gap. Foreign inflation is required to account for strong inflation spillover effects. The real exchange rate again enters due to incomplete pass-through (Monacelli, 2005). Notice that the real exchange rate equation allows this variable to respond to short run movements in monetary and real developments in both economies.

In the light of the zero restrictions imposed in the lag matrices, the mutual orthogonality of the shocks ε_t is not statistically enforced and this is assessed in the next appendix.

2 Appendix 2: Data and Additional Results

2.1 Data

Euro Area GDP data are from the November 2008 Area Wide Model (AWM) database (developed within the European Central Bank; see Fagan, Henry and Mestre, 2005). However, the construction of monetary series in the AWM database using fixed historical (GDP) weights is not not attractive, as it tends to overweight 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, Dungey, Osborn and Vahid (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. The US data are drawn directly from the FRED database, made available by the Federal Reserve Bank of St Louis. The data used in our model are shown in Figure A.2.1.

2.2 Unit Roots and Cointegration

A unit root analysis clearly supports the $I(1)$ nature of both (log) output series and the (log) real exchange rate, with none of the three series y_t^{US}, y_t^{EA} or q (all measured in logarithms) rejects the unit root null hypothesis at even the 10% level. Although cointegration between the two output series alone is not supported, a single cointegrating vector is indicated when the real exchange rate is included[1].

When estimated as the first step of an Engle-Granger procedure, this yields

$$y_t^{EA} = 0.7323 y_t^{US} + 0.0362 q_t + 7.3708 + ecm_t \tag{14}$$

where ecm_t is the estimated disequilibrium at time t. Note that (14) implies differential trend rates of output growth in the two economies, as also indicated by the data characteristics evident in the output series of Figure 1. Our modelling employs the coefficients of (14) to define the error-correction variable that is embodied in the results reported in Section 4 of the text.

2.3 Residual Correlations

The SVECM residuals have relatively small correlations as shown Table 2.1 and these are considered sufficiently close to zero for the residuals to be treated as orthogonal. 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}), suggesting that further cross-country effects may exist. The the cross-correlation of 0.057 between r_t^{US} and r_t^{EA} supports our approach of modelling monetary policy as being focussed on domestic variables in each case.

Table A2.1: 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}	.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

[1] 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.

Figure A.2.1 Data Graphs

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