Sources of sterling real exchange rate fluctuations, 1973-94

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Introduction

"There is no simple relationship between exchange rate changes and subsequent inflation"
Bank of England *Inflation Report*, May 1995.

What are the price (inflation) implications of an exchange rate movement? Several factors have to be borne in mind in answering this question. First, exchange rates and prices are both *endogenous* variables. As such, exchange rate changes constitute one (potentially important) *channel* through which *exogenous* shocks affect prices. But they do not constitute an independent source of price fluctuations *unless* the authorities allow wage bargaining and price setting behaviour to be affected by such changes – the "second round" effects. Second, and directly following from the above, we need to identify the (unobservable) *source* of any exchange rate change to answer the question. This is especially important as both the sign and magnitude of the direct ("first round") price effects depend on the type of shock underlying the exchange rate change.

The *sources* of *real* exchange rate movements is a long-debated issue. The "disequilibrium" approach (Dornbusch (1976), Mussa (1982)) posits that sluggish price adjustment means that nominal shocks will play a large role.[2] Another prominent theory[3] is the "equilibrium" approach of Stockman (1987, 1988). This stresses that real shocks, with large permanent components, are likely to be the source of real exchange rate fluctuations.[4]

But have exchange rate changes actually constituted an important *channel* through which exogenous shocks have affected prices? To determine this we also need to identify the sources of price movements.[5] The answer is clearly "no" if price fluctuations are attributable to different types of shocks to exchange rate movements. A priori the types of shocks that might potentially underlie price movements are similar to the potential sources of exchange rate movements; an exchange rate is, after all, a relative price.

To investigate these issues we follow Clarida and Gali (1994) in estimating UK-centred two country open economy macro models in the spirit of Dornbusch (op cit). The analysis is conducted with the United States, Japan, Germany and France in turn as the foreign countries. We use the Blanchard and Quah (1989) structural VAR (SVAR) approach to identify three structural shocks: (i) *real* AS (aggregate supply) shocks, which include all labour market factors, such as

1 Monetary Assessment and Strategy Division, Bank of England. The views expressed are those of the authors and not necessarily those of the Bank of England. The following has benefited from comments by Danny Quah, Clive Briault, Andrew Haldane and Frank Smets at the BIS. Remaining errors are, of course, entirely our responsibility. Our thanks go to Siobhan Phillips for excellent research assistance.

2 The well documented strong positive correlation between real and nominal exchange rate movements supports the disequilibrium view. But the Meese and Rogoff (1988) empirical rejection of the predicted strong correlation between real interest differentials and real exchange rate changes called the approach into question.

3 Other popular theories include the monetary approach (which is the long-run solution to Dornbusch (op cit), the portfolio balance approach and the currency substitution approach.

4 The Huizinga (1987) finding that a high proportion of real exchange rate variation is due to permanent shocks (real exchange rates contain unit roots) supports the equilibrium view.

5 Clarida and Gali (op cit) paid less attention to this issue than we do.

differential productivity developments, that shift the aggregate supply curve; (ii) *real* IS (goods market) shocks, encompassing exogenous changes to *real* relative domestic absorption due to shifts in consumption, investment, government expenditure and home/foreign goods tastes; and (iii) *nominal* LM (money market) shocks, reflecting shifts in both relative money supplies and relative money demands. As the models are relative ones, we only consider the effects of *asymmetric* shocks.

To identify the model we impose three theory-derived *long-run* restrictions.[6] The first two restrictions are that both IS shocks and LM shocks have zero long-run effects on the level of relative output (which is entirely supply determined). The final restriction is that LM shocks have zero long-run effects on the level of the real exchange rate. The strength of these restrictions is their generality and uncontentious nature. The remaining responses – long-run and short-run – are entirely data determined, rather than being *imposed.*

The framework adopted is highly suited to answering the questions at hand because: (i) it takes account of both *real* and *nominal* shocks (AS and IS shocks represent real perturbations, while LM shocks are nominal ones); and (ii) it allows us to uncover the contribution of each of the *unobservable* structural shocks to the observed exchange rate and relative price (UK consumer prices minus their foreign equivalents) movements.

Our main findings are as follows. First, IS shocks constituted the main source of sterling real and nominal exchange rate movements.[7] AS shocks were the secondary source of these fluctuations, while LM shocks played extremely limited – and usually statistically insignificant – roles, even at short horizons. The dominance of real (IS and AS) shocks as sources of sterling exchange rate movements is more *consistent* with the Stockman (op cit) equilibrium view than the Dornbusch (op cit) disequilibrium approach. And combined with the estimated impulse response functions these results imply that the sterling exchange rate depreciations over the floating rate period have had largely benign relative price implications. In particular, we find that a 10% nominal sterling depreciation is most likely to be associated with a small (around 1%) *fall* in UK relative prices.

Second, the variation of UK relative prices was due mainly to LM shocks. Of the real shocks, the influence of AS shocks was most apparent. This strong contrast with the exchange rate results indicates that sterling exchange rate fluctuations have not constituted an important channel through which exogenous shocks have been translated into price fluctuations.

Third, the estimated dynamic responses of the variables to each of the three shocks are highly theory consistent. Fourth, the periods in which the SVARs indicate that particular shocks were most important correspond to observable relative productivity, domestic demand and monetary aggregate developments. Both these findings indicate that the SVAR representations of the data have a high economic content.

The remainder of the paper is organised as follows. Section 1 describes the rational expectations open economy stochastic exchange rate model that underlies the empirics and outlines the structural VAR approach. Section 2 presents the results, the implications of which are discussed in Section 3. Section 4 examines how the SVARs explain sub-period exchange rate and price movements, while the final section concludes.

6 These restrictions *exactly* identify the model. They cannot, therefore, be directly tested. We determine the economic content of the SVARs by implementing several informal "overidentifying" tests commonly used in the literature.

7 This similarity of the real and nominal exchange rate results reflects the fact that these two series closely tracked each other.

1. Method

1.1 Structural exchange rate model

The Obstfeld (1985) stochastic two country version of the Dornbusch (op cit) model underlies our empirics. This serves the two usual purposes in the SVAR literature. First, it provides the economic underpinnings of the long-run identifying restrictions imposed. Second, it supplies the theoretical priors to compare the estimated dynamic responses against – the important "overidentifying" test of SVARs. But, importantly, the empirical strategy is not tied to this particular model. A number of mainstream models display the same long-run conditions and predicted short run responses.

The Obstfeld (op cit) model is a relative one, defined in terms of home country (UK) variables minus foreign country ones. This formulation means that only the effects of *asymmetric* shocks are considered. Four equations make up the model. First, an open economy goods market relationship, where IS shocks are introduced. Second, a relative money market equilibrium condition, where LM shocks are introduced. Third, a price setting rule. Finally, a nominal UIP condition. Appendix A outlines the model in more detail.

Table 1 summarises the long-run and short-run model solutions, which are derived in Appendix A. The long-run solution occurs when prices become perfectly flexible and rational expectations hold. Relative output is then determined entirely by supply shocks – a vertical long-run aggregate supply curve. The zero long-run effects of IS and LM shocks on the level of relative output constitute two of the three restrictions required to achieve identification. These restrictions allow us to distinguish AS shocks from the other two shocks. The final identifying restriction is that LM shocks have no long-run effect on the real exchange rate, which allows us to distinguish between IS and LM shocks.

Table 1
Long-run (LR) and short-run (SR) responses (to positive shocks)

Shock/variable		Relative output	Real exchange rate	Relative prices	Nominal exchange rate
AS	LR SR	+ + (< LR)	+ + (< LR)	– – (< LR)	? (+) ? (+< LR?)
IS	LR SR	Zero + TempComp	– PermComp – (< LR)	+ TempComp + (< LR)TempComp	? (–) ? (–< LR?)
LM	LR SR	Zero +	Zero +	+ equal. + (< LR)	+ equal + (> LR?)

Key: +(–) = increase (decrease); ? = ambiguous response; >(<) = greater (less) than ; equal = response equals size of shock; TempComp (PermComp) = only temporary (permanent) component of shock; exchange rate *increases* denote depreciations.

Both AS and IS shocks are *capable* of affecting the long-run real exchange rate. Positive AS shocks unambiguously produce long-run real *depreciations*; an improvement in competitiveness is required to stimulate demand for the extra output generated by such shocks. Conversely, positive IS shocks produce real *appreciations*. But the real exchange rate movements will only be permanent to the extent that the IS shock is permanent. This is because the foreign exchange market discounts the reversal of the temporary component of IS shocks (Appendix A shows this algebraically).

The long-run relative price/output responses summarised in Table 1 are mainly intuitive. The exception is that only the *temporary* component of IS shocks affect long-run relative prices. This is because the *permanent* component of IS shocks moves world real/nominal interest rates, leaving relative interest rates unchanged. And relative output, the other argument in the LM curve, is, by assumption, unchanged. For the LM relationship to continue holding requires relative prices, and hence real money balances, to be invariant to the shock. Positive *permanent* IS shocks thus induce home and foreign prices to increase by the same proportion in the long-run, leaving relative prices unchanged.

Only LM shocks have unambiguous long-run *nominal* exchange rate[8] responses – positive shocks producing depreciations that equal the size of the shock. The indeterminate long-run IS and AS shock effects reflect the real exchange rate and price effects working in opposite directions. But intuitively we expect both nominal exchange rates[9] and relative prices to move to facilitate a required real exchange rate movement. Positive (negative) AS (IS) shocks will then produce nominal depreciations.[10]

In the short-run, when prices are sticky, all shocks potentially affect all endogenous variables. Appendix A proves the intuitive result that the short run *price* effect of each of the shocks is less than the long run equivalents. We also confirm the usual result that positive LM shocks *depreciate* the real exchange rate when prices are sticky. And price stickiness means that real exchange rates *undershoot* their long-run responses following AS and IS shocks. The nominal exchange rate may either undershoot or overshoot in the short-run, depending upon parameters such as the responsiveness of relative output to the real exchange rate and interest rate differentials. Relative output is *demand* determined in the short-run, with positive LM shocks and the temporary component of positive IS shocks raising relative output. Finally, price stickiness reduces the output effect of AS shocks.

1.2 Structural VAR overview

The Blanchard and Quah (op cit) SVAR approach enables us to transform a VAR into its structural moving average representation. The impact of three shocks on the joint long-run behaviour of the three endogenous variables – relative output, the real exchange rate and relative prices – are exploited to achieve identification. The method has several benefits. First, the *short-run* dynamics, about which there is considerably less agreement in the literature, are left completely unconstrained (data determined). Second, the method side-steps the well-known problems with VARs: the need to impose *contemporaneous* restrictions, ordering problems and the Cooley and LeRoy (1985) critiques.[11] Finally, the forecast error variance decompositions, impulse responses, historical decompositions and shock series generated can be given structural interpretations. To take account of the fact that the structural impulse responses/variance decompositions are based upon *estimated* VAR coefficients we use Monte Carlo techniques to put error bands on the point estimates. Appendix B provides a full description of the mechanics of identification.

8 Obtained by combining the long-run relative price and real exchange rate expressions.

9 Appendix A details the factors that determine the extent of this nominal exchange rate response.

10 The nominal depreciation following negative IS shocks is intuitively due to the fall in domestic interest rates induced by an inward shift in the IS curve provoking a capital outflow.

11 Keating (1992) is a good introduction to the SVAR literature. SVARs, however, are not without their detractors. Faust and Leeper (1994) outline several potential problems with SVARs identified with purely long-run restrictions.

2. Results

2.1 Estimation

We implement the above procedures by estimating trivariate SVARs of relative output (y_t), the real exchange rate (q_t) and relative prices (p_t). Each of the variables is defined in terms of home (UK) variable minus the foreign equivalent. For example, $p_t = p_t^h - p_t^f$, where superscript *h* (*f*) denotes a home (foreign) variable. Since we take natural logarithms of all the individual country variables,[12] the relative measures constitute ratios. The real exchange rate (q_t) is constructed by subtracting relative prices from the nominal exchange rate (s_t). As s_t is defined as the number of units of domestic currency required to purchase a unit of foreign currency, rises in q_t (s_t) constitute real (nominal) depreciations. The model was estimated on quarterly data between 1973 Q1 and 1994 Q4. Real GDP is the output measure used, while consumer price indices constitute the relative price measure and are used in the construction of the real exchange rates. The nominal exchange rate component of the real exchange rates are quarterly average spot rates.

The ADF tests (Tables 2 and 3) indicate that the variables are all I(1). Theory does not suggest that we can expect the three variables to be cointegrated (the matrix determining the long-run effects of the shocks on the endogenous variables is lower triangular). And the Johansen tests (Table 4) support this prediction. The null of no cointegration is only rejected in the UK-Japanese case. But we concluded that no meaningful long-run relationship was present even here because: (i) the rejection of the null only occurred at the 90% confidence level; (ii) the resulting residuals appeared non-stationary; and (iii) the long-run coefficients had no economic content. The first stage VARs were, therefore, estimated in first differences.[13]

Table 2
ADF tests on levels of variables*

Country/variable	Relative output	Real exchange rate	Relative prices
United Kingdom-United States	–2.2	–2.6	–3.0
United Kingdom-Japan	–1.9	–2.5	–1.6
United Kingdom-Germany	–2.1	–2.1	–1.6
United Kingdom-France	–1.9	–1.8	–2.4

* ADF(4) with trend test (95% critical values = –3.5).

The first stage VAR lag lengths were selected using a combination of sequential likelihood ratio tests and the Akaike information criteria. We attached higher weight to the former because of the DeSerres and Guay's (1995) finding that Akaike (or Schwartz) criteria tend to select an insufficient number of lags. Our approach eliminates the possibility of too short a lag length biasing the estimates of the structural parameters (DeSerres and Guay (op cit)). The tests indicated that 3 lags were appropriate in the UK-US system, 1 lag in the UK-Japanese and UK-German systems and 4 lags in the UK-French systems. Running the systems with higher number of lags (up to 8) produced only minor changes in results and meant that shorter periods of data could be examined.

12 Except interest rates.

13 The approach of King, Plosser, Stock and Watson (1989) would need to be applied if cointegration were found.

Table 3
ADF tests on first differences of variables*

Country/variable	Relative output	Real exchange rate	Relative prices
United Kingdom-United States	–5.2	–4.8	–3.9
United Kingdom-Japan	–3.1	–4.6	–4.4
United Kingdom-Germany	–4.2	–3.2	–4.1
United Kingdom-France	–4.2	–4.8	–3.9

* ADF(4) without trend test (95% critical values = –2.9).

Table 4
Johansen cointegration tests[1]

Country/variable	Eigenvalue test[2]	Trace test[3]
United Kingdom-United States	7.51	14.78
United Kingdom-Japan	19.80	29.22
United Kingdom-Germany	13.20	24.54
United Kingdom-France	12.63	22.47

1 Four lags in VAR.
2 95% critical value = 21.07.
3 95% critical value = 31.52.

We investigated possible VAR instability by undertaking several variants of recursive Chow tests. Policy regime changes in both the UK and abroad constitute one potential source of instability. The one step ahead tests indicate that *outliers* are present, especially in the exchange rate equations; Figure 1 presents the United Kingdom-United States system plots.[14] But the n-step tests indicate that these outliers did not translate into *regime shifts* – see Figure 2 for the UK-US system – which we are more concerned about. Moreover, these benign results – which are not unusual in the literature[15] – were not a function of poorly specified VARs.[16]

14 Interestingly, the major £/$ outlier occurs around 1985, tying in with the Evans (1986) finding that the £/$ was subject to a speculative bubble between 1981-84 and the general perception of dollar misalignment around this period.

15 For example, Evans and Lothian (op cit) and Sarantis (1993) uncovered no evidence of instability in their dollar and sterling based analyses over periods similar to our own.

16 Full VAR diagnostics are available on request from the authors. Importantly, serial correlation was never a problem.

Figure 1
1-step ahead recursive Chow test (outlier test): United Kingdom-United States system

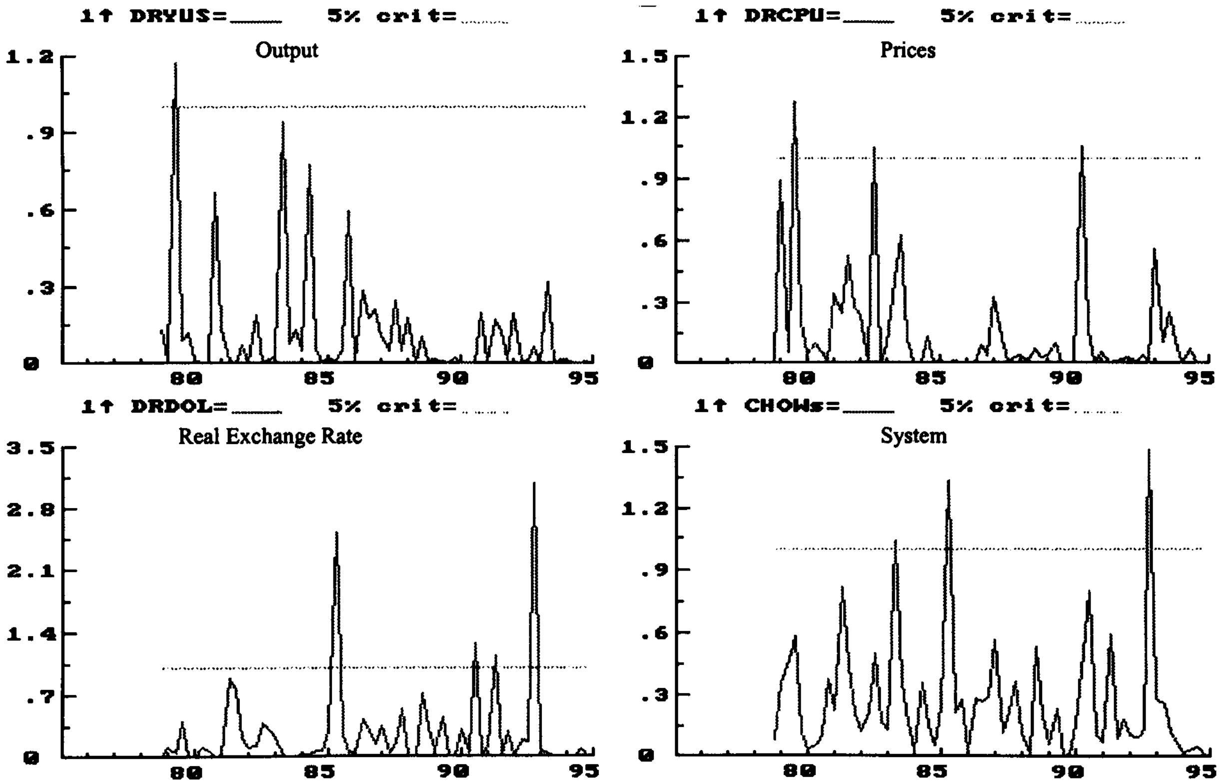
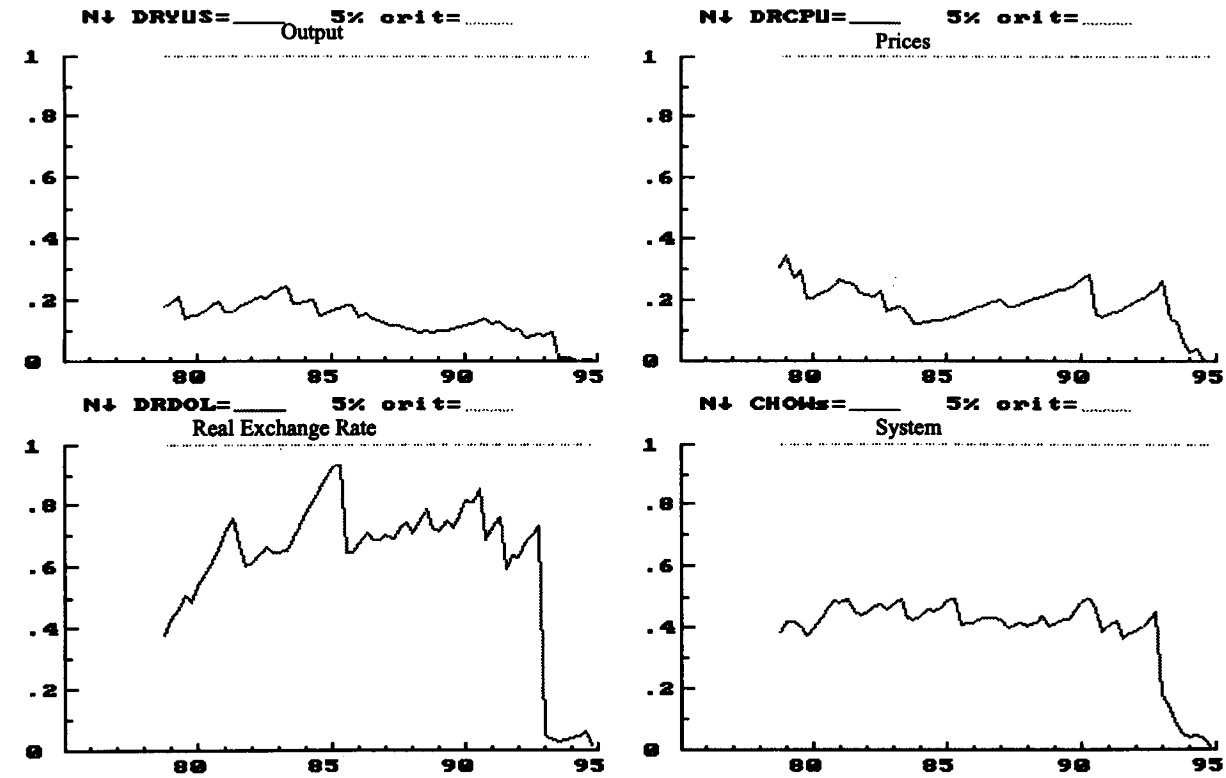


Figure 2
N-step recursive Chow test (regime shift test): United Kingdom-United States system



2.2 Forecast error variance decompositions (FEVDs)

FEVDs tell us which shocks were the primary *sources* of movement in the endogenous variables over the sample period. In each case we calculate the FEVDs on the *levels* of the endogenous variables,[17] as these correspond most closely to the questions we wish to address. The results presented in Tables 5-8 detail, in the top row for every horizon, the *point estimate* of the proportion of the variation in each variable attributable to each shock. The two standard errors[18] associated with these point estimates appear in the lower row in smaller font. This allows us to determine whether the contribution of a particular shock is significantly different from zero at a 95% confidence level.

Table 5
Variance decomposition of real exchange rates

Horizon	£/$			£/Yen		
	AS	IS	LM	AS	IS	LM
1	0.021	0.966	0.014	0.222	0.762	0.016
	0.102	0.143	0.109	0.139	0.145	0.058
2	0.011	0.978	0.011	0.199	0.794	0.007
	0.086	0.122	0.093	0.140	0.144	0.033
4	0.035	0.959	0.005	0.181	0.816	0.003
	0.094	0.113	0.066	0.150	0.152	0.015
8	0.075	0.923	0.002	0.172	0.827	0.001
	0.122	0.129	0.039	0.160	0.161	0.006
12	0.084	0.915	0.002	0.169	0.830	0.001
	0.139	0.142	0.026	0.164	0.164	0.003
16	0.088	0.911	0.001	0.168	0.832	0.001
	0.149	0.150	0.019	0.166	0.166	0.002
20	0.091	0.908	0.001	0.167	0.833	0.000
	0.155	0.156	0.015	0.167	0.167	0.002
Horizon	**£/DM**			**£/FFr**		
	AS	**IS**	**LM**	**AS**	**IS**	**LM**
1	0.093	0.720	0.187	0.217	0.782	0.001
	0.080	0.163	0.145	0.163	0.183	0.074
2	0.112	0.749	0.139	0.200	0.799	0.001
	0.088	0.150	0.116	0.167	0.183	0.062
4	0.136	0.782	0.082	0.244	0.743	0.013
	0.107	0.140	0.073	0.186	0.189	0.050
8	0.157	0.803	0.040	0.249	0.743	0.007
	0.128	0.139	0.035	0.186	0.189	0.026
12	0.167	0.809	0.025	0.252	0.742	0.005
	0.137	0.143	0.021	0.191	0.192	0.018
16	0.171	0.811	0.018	0.252	0.744	0.004
	0.143	0.146	0.014	0.194	0.195	0.014
20	0.174	0.812	0.014	0.252	0.745	0.003
	0.146	0.148	0.011	0.198	0.199	0.011

Key: Top rows detail fraction of variation in variable attributable to each shock. Bottom rows give empirical two standard errors, computed by Monte Carlo simulation.

17 FEVDs on first differences produced similar results.

18 Calculated using 100 draws of Monte Carlo simulations. For computational simplicity, these error bands are portrayed as symmetric. Runkle (1987) and Blanchard and Quah (op cit) illustrate that this is not necessarily the case when bootstrapping methods are used.

2.2.1 Real exchange rates

Table 5 presents the strong result that *IS* shocks were the main source of movements in each of the four sterling real exchange rates considered. IS shocks were most important in determining real £/$ movements, where they accounted for over 90% of movements at all horizons. But they also accounted for at least 75% of the fluctuations in the three other rates, with their importance often rising at longer horizons. *AS* shocks were usually the second most important source of real sterling movements. Their effect was most pronounced, and statistically significant, in the £/Yen and £/FFr cases, where they accounted for around 20% of movements at most horizons.

LM shocks were usually unimportant sources of real sterling fluctuations at all horizons. The only exception is the £/DM rate. But the effect is limited even here – a maximum of 19% – and is only apparent at short horizons. Though an identifying restriction underlies the unimportance of LM shocks at long-horizons, their extremely limited role at short horizons is entirely data generated.

Clarida and Gali (op cit) similarly concluded that LM shocks were unimportant determinants of real $/£ fluctuations. But they found that they played larger roles in real $/DM and $/Yen movements.[19] This might initially suggest that different factors underlie sterling and dollar movements. But there are several reasons for not overplaying these differences. First, movements in both currencies primarily reflect IS shocks. Second, considering a broader range of bilateral rates might blur the above distinction. Indeed, it is noticeable that, on our dataset, LM shocks played virtually no role[20] in real $/FFr fluctuations. And other sterling exchange rates might replicate the higher, though still small, importance of LM shocks in real £/DM fluctuations.

The Rogers (1995) application of the Lastrapes (1992) framework to the $/£ rate also produced results consistent with those presented in this paper. Real (permanent) shocks were found to be the main source of real and nominal $/£ movements. And these results ties in with those of Lastrapes (op cit) on five other dollar rates.[21] But Rogers (op cit) observed that the simplistic model may have been driving these results: nominal (LM) shocks were attributed a higher role in real $/£ fluctuations in his more structured (trivariate) model. In particular, nominal shocks constituted the most important source of real $/£ movements at short horizons (accounting for around 50% of the fluctuations). Evans and Lothian (1993) also concluded that temporary (nominal) disturbances played a significant role in *sub-sample* £/$ movements. But this role was usually small (a maximum of around 15%). A useful cross-check of the robustness of our results, which we postpone for future research, is to apply these alternative frameworks to the sterling exchange rates analysed in this paper.

2.2.2 Relative prices

UK relative price movements were mainly due to *LM* shocks (Table 6). The role of LM shocks was most pronounced in UK-US prices, where they accounted for 80% of movements at the shortest horizon and 97% inside a year. But they also accounted for approximately 70% of the variation of UK-Japanese and UK-German prices, with comparatively little variation across horizons. Finally, LM shocks were the second most important determinants of UK-French price movements at every horizon, accounting for up to 44% of the fluctuations.

19 Clarida and Gali found that LM shocks accounted for up to 36% (53%) of real $/Yen ($/DM) movements. The point estimates we obtain on our (longer) dataset are lower, but not significantly different.

20 A maximum of 0.6%.

21 Lastrapes (op cit) excluded the $/£ rates from his dollar-centred work because of evidence of them being I(0). On our longer dataset this is not a problem.

Table 6
Variance decomposition of relative prices

Horizon	United Kingdom-United States			United Kingdom-Japan		
	AS	IS	LM	AS	IS	LM
1	0.123	0.040	0.837	0.288	0.049	0.663
	0.190	0.152	0.207	0.150	0.077	0.156
2	0.053	0.035	0.913	0.276	0.082	0.642
	0.149	0.149	0.186	0.155	0.080	0.151
4	0.024	0.014	0.962	0.263	0.117	0.620
	0.135	0.132	0.172	0.166	0.089	0.154
8	0.008	0.005	0.986	0.255	0.139	0.607
	0.127	0.132	0.170	0.174	0.096	0.160
12	0.005	0.003	0.992	0.252	0.145	0.603
	0.130	0.133	0.174	0.177	0.099	0.163
16	0.003	0.002	0.995	0.251	0.148	0.601
	0.133	0.134	0.176	0.179	0.101	0.165
20	0.003	0.002	0.996	0.250	0.150	0.600
	0.135	0.135	0.178	0.179	0.101	0.166

Horizon	United Kingdom-Germany			United Kingdom-France		
	AS	IS	LM	AS	IS	LM
1	0.327	0.164	0.509	0.662	0.047	0.292
	0.210	0.171	0.197	0.230	0.126	0.184
2	0.270	0.163	0.567	0.584	0.050	0.366
	0.192	0.165	0.189	0.230	0.121	0.187
4	0.223	0.160	0.617	0.539	0.094	0.367
	0.180	0.164	0.186	0.229	0.133	0.185
8	0.196	0.156	0.648	0.485	0.093	0.422
	0.174	0.164	0.187	0.229	0.130	0.196
12	0.187	0.155	0.658	0.467	0.098	0.435
	0.173	0.164	0.188	0.231	0.134	0.201
16	0.183	0.155	0.662	0.460	0.099	0.441
	0.172	0.164	0.188	0.232	0.136	0.204
20	0.181	0.154	0.665	0.456	0.100	0.444
	0.172	0.164	0.188	0.233	0.137	0.205

Key: Top rows detail fraction of variation in variable attributable to each shock. Bottom rows give empirical two standard errors, computed by Monte Carlo simulation.

AS shocks also played large, and statistically significant, roles. They were the main source of UK-French price movements (up to 66% at short horizons) and the second most important source of fluctuations in the remaining series. *IS* shocks were uniformly the least important source of relative price fluctuations. Their role was most pronounced at long horizons, where they accounted for at least 10% of the observed movements (except in the UK-US case).

2.2.3 Nominal exchange rates

LM shocks played a larger role in sterling *nominal* exchange rate movements (Table 7) than in the real exchange rate equivalents. But this role was still small. The maximum effect was 35% (£/DM), but was more frequently under 15%. This larger role obviously reflects the dominant role that LM shocks played in relative price movements. But their effect remains extremely limited because the nominal exchange rate paths largely mirrored their real rate equivalents. This close tracking means that *IS* shocks again constituted the main source of nominal rates movements. This dominance was most pronounced in the £/$ and £/FFr rates. *AS* shocks also often underlay some of the nominal rate movements, especially of £/DM and £/Yen rates.

Table 7
Variance decomposition of nominal exchange rate

Horizon	£/$			£/Yen		
	AS	IS	LM	AS	IS	LM
1	0.006	0.911	0.083	0.136	0.756	0.108
	0.088	0.176	0.169	0.108	0.146	0.105
2	0.009	0.903	0.089	0.121	0.794	0.085
	0.097	0.176	0.167	0.112	0.134	0.073
4	0.039	0.879	0.081	0.110	0.823	0.067
	0.118	0.170	0.142	0.118	0.129	0.046
8	0.077	0.818	0.105	0.104	0.838	0.058
	0.147	0.167	0.118	0.124	0.128	0.030
12	0.083	0.791	0.126	0.102	0.842	0.056
	0.158	0.166	0.109	0.126	0.128	0.026
16	0.085	0.775	0.140	0.101	0.845	0.054
	0.164	0.167	0.104	0.127	0.128	0.025
20	0.086	0.764	0.149	0.101	0.846	0.054
	0.169	0.170	0.102	0.127	0.128	0.024
Horizon	**£/DM**			**£/FFr**		
	AS	**IS**	**LM**	**AS**	**IS**	**LM**
1	0.327	0.613	0.350	0.087	0.905	0.008
	0.208	0.193	0.196	0.132	0.152	0.096
2	0.270	0.618	0.341	0.061	0.911	0.028
	0.188	0.177	0.177	0.120	0.142	0.099
4	0.223	0.629	0.324	0.049	0.852	0.099
	0.170	0.166	0.154	0.124	0.157	0.118
8	0.196	0.645	0.303	0.029	0.868	0.103
	0.160	0.157	0.135	0.117	0.143	0.099
12	0.187	0.654	0.293	0.021	0.863	0.116
	0.157	0.155	0.130	0.116	0.135	0.089
16	0.183	0.658	0.287	0.016	0.861	0.123
	0.155	0.155	0.128	0.119	0.132	0.085
20	0.181	0.661	0.283	0.014	0.859	0.127
	0.155	0.155	0.128	0.122	0.132	0.083

Key: Top rows detail fraction of variation in variable attributable to each shock. Bottom rows give empirical two standard errors, computed by Monte Carlo simulation.

2.2.4 Relative output

UK relative output fluctuations were primarily attributable to AS shocks (Table 8). This ties in with the Holland and Scott (1995) results. The first and second identifying restrictions (see Section 1) obviously underlie this finding at long horizons. But it is again data generated at shorter horizons. AS shocks accounted for over 80% of movements in most of the output series after two quarters. The only exception was the large (60%) role that LM shocks played in *short horizon* UK-French movements.

Table 8

Variance decomposition of relative output

Horizon	United Kingdom-United States			United Kingdom-Japan		
	AS	IS	LM	AS	IS	LM
1	0.877	0.066	0.057	0.799	0.139	0.062
	0.203	0.107	0.179	0.127	0.106	0.074
2	0.903	0.045	0.053	0.885	0.080	0.035
	0.190	0.097	0.168	0.082	0.067	0.043
4	0.946	0.025	0.029	0.947	0.037	0.016
	0.145	0.064	0.127	0.041	0.033	0.020
8	0.969	0.014	0.017	0.976	0.017	0.007
	0.100	0.040	0.087	0.018	0.015	0.008
12	0.978	0.010	0.012	0.985	0.011	0.005
	0.071	0.028	0.062	0.011	0.009	0.005
16	0.983	0.007	0.009	0.989	0.008	0.003
	0.052	0.021	0.045	0.008	0.007	0.004
20	0.987	0.006	0.007	0.991	0.006	0.003
	0.016	0.016	0.016	0.005	0.005	0.005

Horizon	United Kingdom-Germany			United Kingdom-France		
	AS	IS	LM	AS	IS	LM
1	0.785	0.056	0.160	0.345	0.002	0.653
	0.180	0.095	0.145	0.199	0.076	0.206
2	0.837	0.037	0.126	0.439	0.001	0.560
	0.147	0.073	0.113	0.199	0.073	0.196
4	0.900	0.021	0.079	0.631	0.002	0.367
	0.100	0.051	0.071	0.164	0.060	0.156
8	0.951	0.010	0.039	0.829	0.010	0.161
	0.052	0.028	0.035	0.089	0.043	0.074
12	0.968	0.007	0.025	0.892	0.006	0.102
	0.033	0.018	0.022	0.055	0.029	0.044
16	0.977	0.005	0.019	0.921	0.004	0.075
	0.023	0.013	0.016	0.039	0.021	0.032
20	0.982	0.004	0.015	0.938	0.003	0.059
	0.010	0.010	0.010	0.016	0.016	0.016

Key: Top rows detail fraction of variation in variable attributable to each shock. Bottom rows give empirical two standard errors, computed by Monte Carlo simulation.

2.3 Impulse responses

Figures 3-6 present the estimated dynamic responses of the variables to each of the structural shocks. The dark line in the figures represent the *point estimates* of the response of the *levels* of each of the variables to a one standard deviation perturbation to each the three shocks. The lighter lines on either side of these point estimates represent the two standard deviation error bands. Like Clarida and Gali (op cit) we find that the signs of these responses are highly consistent with our theoretical priors. Moreover, the relative magnitudes of the responses are also sensible: exchange rates respond by more than relative prices which in turn respond by more then relative output. Our results, therefore, pass the important SVAR "overidentifying" test. This means that we can be confident of the economic content of the FEVDs.

Figure 3

United Kingdom-United States responses

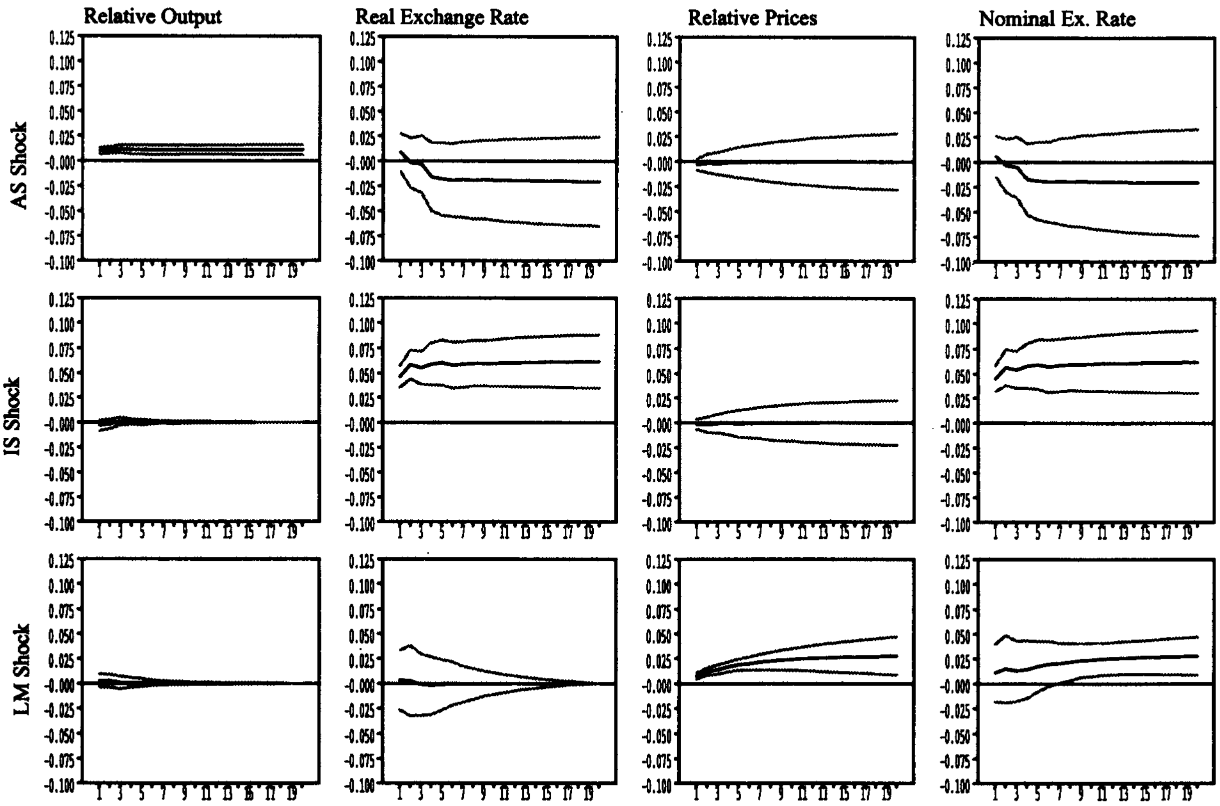


Figure 4

United Kingdom-Japanese responses

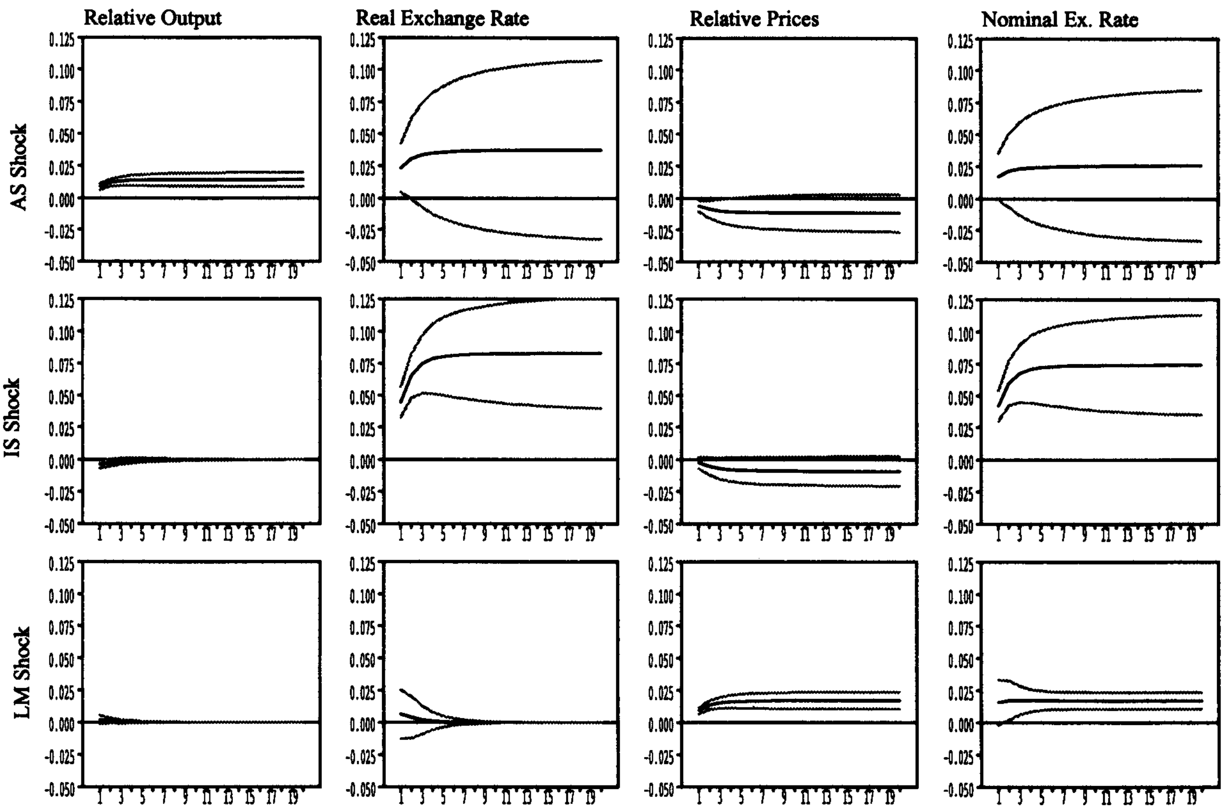


Figure 5
United Kingdom-German responses

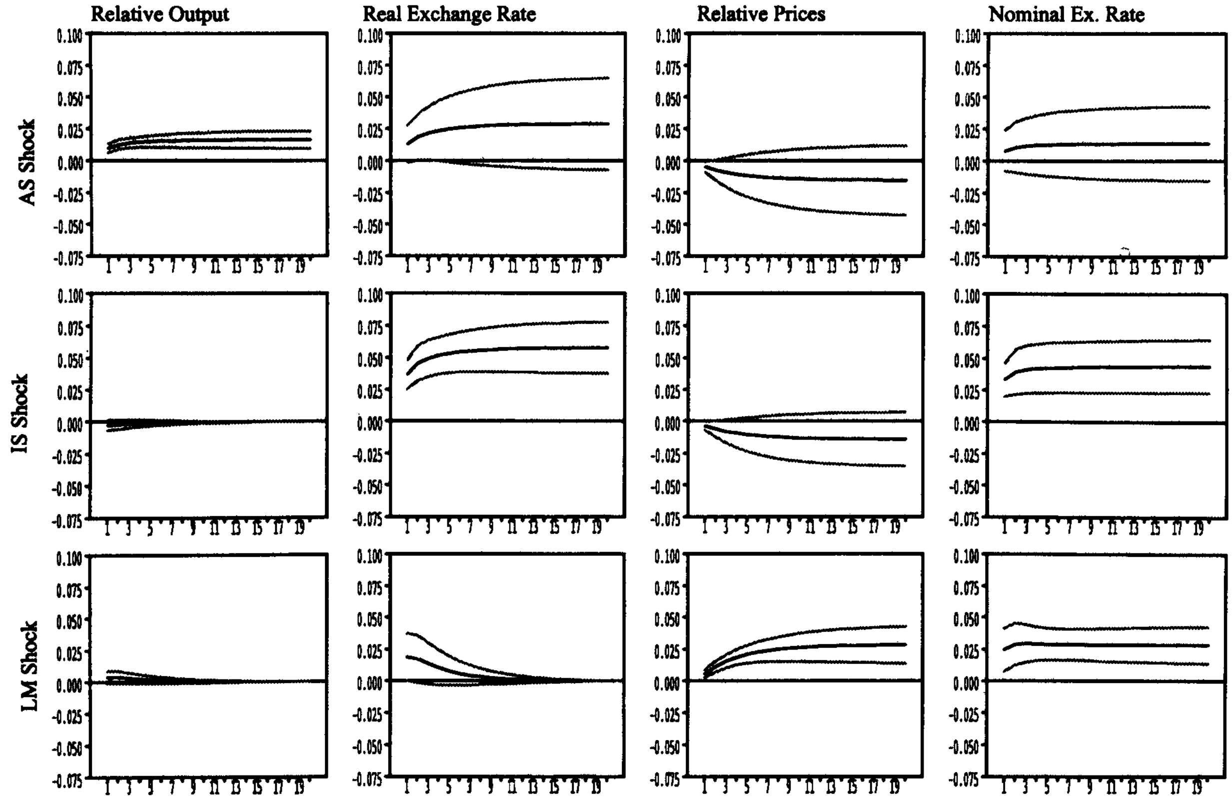
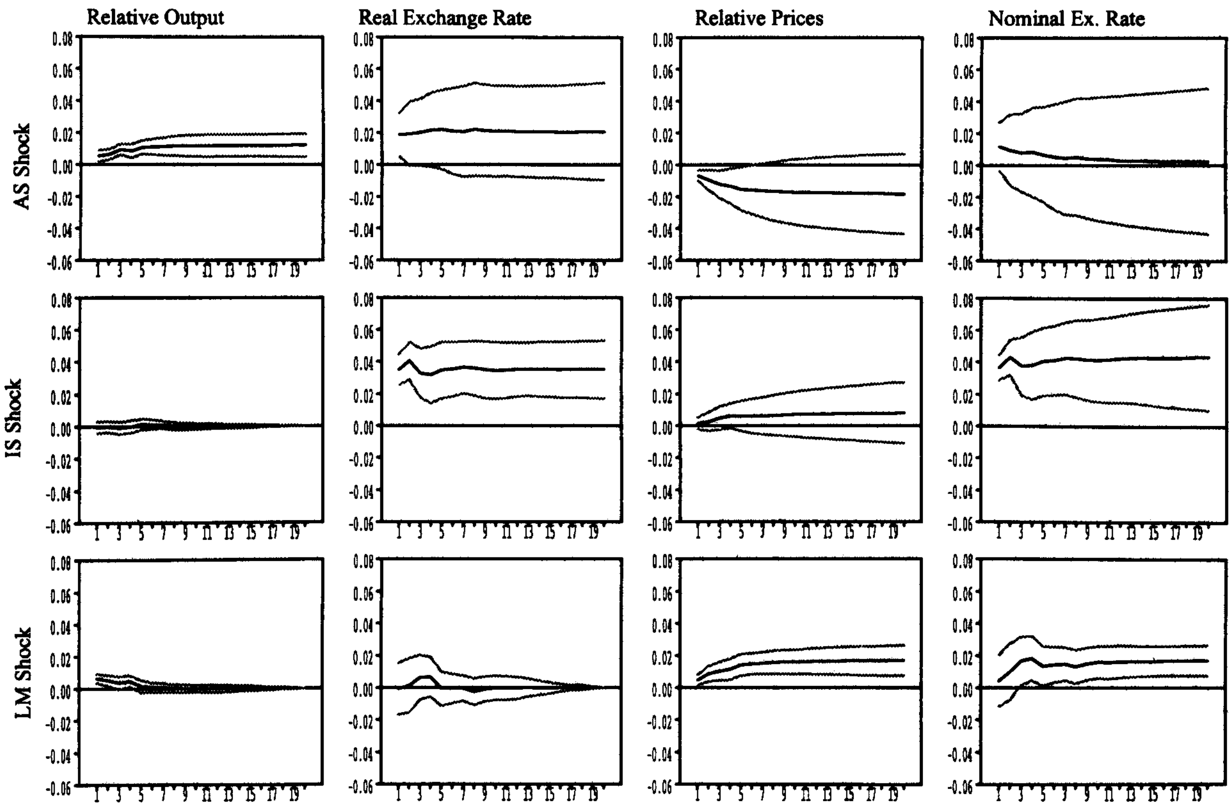


Figure 6
United Kingdom-French responses



2.3.1 Responses to AS shocks

AS shocks produce dynamic responses which are highly theory consistent. Positive (benign) AS shocks usually generate falls in relative prices, real exchange rate depreciations and rises in relative output. The only counterintuitive response is the real £/$ *appreciation.* Interestingly, Clarida and Gali (op cit) also uncovered exactly this "perverse" real $/£ response.

Relative prices respond sluggishly to AS shocks, uniformly taking at least 8 quarters to approach their new long-run equilibria. This price stickiness is most apparent in UK-French prices, which take 12 quarters to "level off". Relative prices usually fall by between 1.1%-1.6% in the long-run following positive AS shocks. The exception is the much smaller UK-US response. The long-run real exchange rate responses are, at between 1.9% and 3.5%, considerably larger and more dispersed. Though real exchange rates adjust quicker than relative prices, this adjustment is again comparatively slow (full adjustment taking up to 7 quarters). These responses mean that nominal exchange rates, as expected, *depreciate* (slowly) following positive AS shocks. The long-run relative output responses are, at between 1.0% and 1.5%, fairly uniform.

2.3.2 Responses to IS shocks

The responses to IS shocks require a little more interpretation. IS shocks usually produce, across countries and variables, counterintuitive responses – falls in relative prices and output and real exchange rate depreciations. But these results are actually benign. This is because, as Faust and Leeper (1994) note, the SVAR method does not tie down the *sign* of *each* of the elements on the principal diagonal of the structural impulse response matrices. This indeterminacy arises from having to solve what is essentially a quadratic expression – which can produce either a positive or a negative solution.[22] This means that we can only conduct the "overidentifying" in terms of the consistency of the *relative* responses. The *uniformly* "incorrectly" signed responses indicate that *negative* IS shocks have been identified. The responses to these negative shocks are, therefore, "correctly" signed. *Positive* IS shocks results which are easier to interpret, can be obtained by simply multiplying the associated responses and IS shock series[23] by -1.

This is an important point to appreciate because IS shocks have been found to underlie the majority of sterling exchange rate movements. But there is also a corollary. Because the "incorrectly" signed £/FFr response is not matched by counterintuitive output and price responses, we have less grounds for suspecting that negative UK-French IS shocks have been identified. Our finding that IS shocks underlay most £/FFr movements may, therefore, be on shaky ground.

Relative prices again *rise* sluggishly following *positive* IS shocks, taking up to nine quarters to approach their long-run responses. Interestingly European (UK-German and UK-French) prices appear stickiest. The UK-US responses again constitute the main outlier, their long-run movements lying considerably below the 0.8% to 1.3% range of the remaining relative prices.

The real exchange rate *appreciations* following positive IS shocks are again large and quite dispersed – the long-run responses lying between 3.3% (£/FFr) and 7.8% (£/Yen). The adjustment to the new long-run is usually smooth and comparatively protracted; it takes up to 6 quarters for steady state to be reattained. Interestingly, there is some evidence of real £/FFr overshooting. But this probably reflects the comparative volatility of this response. As expected, positive IS shocks also produce *nominal* appreciations. The increases in relative output following positive IS shocks are uniformly small, peaking at 0.4%.

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22 In particular the signs of the each of the principal diagonals of C_0 solved in equation (B4) are indeterminate. If C_0^a satisfies (B4) then so will $C_0^b = C_0^a H$, where H is a diagonal matrix with either 1 or -1 on the diagonal.

23 The fact that that transformed IS structural shock series (not shown) have considerably more intuition adds further weight to the argument that negative IS shocks have been uncovered.

2.3.3 Responses to LM shocks

LM shocks generate responses that uniformly accord with our theoretical priors. A positive LM shock produces a temporary rise in relative output, a temporary real exchange rate depreciation[24] and relative price increases. Finally, as expected, such shocks produce *nominal* depreciations.

Relative prices adjust slowly to LM shocks, typically taking around 10 quarters to adjust more or less fully.[25] The long-run response are, at between 1.7% and 2.9%, reasonably consistent across the country pairs. The temporary real exchange rate depreciations are, except for the £/DM rate, relatively short-lived – reaching their zero long-run effects within 6 quarters.[26] The short lived real exchange rate responses mean that the nominal exchange rate responses largely mirror the relative price responses at all but short horizons.

Our estimates of the speed of adjustment of nominal sterling exchange rates to LM shocks differ from the existing dollar based findings. Clarida and Gali (op cit) and Eichenbaum and Evans (1993) found that dollar rates take around two years to respond fully to LM shocks and monetary *policy* shocks respectively. While we uncover a similar lag in the £/$ responses, this is not a general feature of our results. In particular, the £/Yen rate adjusts quickly and the £/DM and £/FFr rates overshoot slightly in the short-run. This suggests that the dollar based results may not hold for other currencies. Clearly further work is required on this issue.

3. Implications

So what are the price implications of an exchange rate movement? Our results have confirmed the theoretical proposition that what matters is the *type* of shock underlying the exchange rate/price movements. In particular, they indicate that the common perception of exchange rate depreciations producing potential inflationary pressures – through their impact on import prices etc. – is usually misplaced. This is because this malign scenario only holds if *LM* shocks underlie the exchange rate/price movements. In contrast, the AS and IS shocks required to produce depreciations bring forth relative price *falls*. Moreover, these are precisely the shocks that our results indicate have been the major sources of sterling exchange rate movements.[27] And the major source of UK relative price movements, LM shocks, have been unimportant sources of sterling exchange rate fluctuations. This means that, according to our results, sterling exchange rate movements have not been a major channel through which shocks have affected UK relative prices.

The impulse responses allow a quantification of these arguments. We consider the relative price_implications of a 10% *nominal*[28] sterling depreciation due entirely to each of the shocks in turn. To avoid any perverse short-run dynamic effects and side-step problems with long-run restrictions being imposed, we consider the effect of the depreciation occurring 3 quarters after the

24 These temporary responses reflect the second and third identifying restrictions respectively (see Section 1).

25 UK-US prices appear stickiest, taking over three years to reach any kind of plateau.

26 Again these short-run responses are entirely data generated. They do not, in particular, reflect the long-run horizon or the VAR lag lengths employed. For example, the long-lived £/DM response arises from a VAR with only one lag.

27 The short-term role of nominal shocks in £/DM movements is the minor exception.

28 The fact that the nominal responses in our model are *derived* from the real exchange rate and relative price responses is potentially problematic. This is especially the case when LM shocks are considered – the fact that real exchange rate responses often quickly asymptote to zero means that the nominal exchange rate responses mirror the relative price responses at all but short horizons. A framework that directly models the nominal exchange rate would side-step this problem.

shock hits the economy. We also exclude incorrectly signed responses[29] and only consider the average of the point estimate responses. In the unlikely case that (positive) *LM* shocks underlie the depreciation, it is accompanied by an initial 7.5% *rise* in relative prices, increasing to 10% after a further 3 quarters. In the more likely case of (positive) *AS* shocks producing the depreciation, relative prices *fall* by 9.2% on impact and by 12% two years after the shock. In the most likely case of IS shocks causing the depreciation, the accompanying relative price *fall* is much smaller – around 1% on impact, rising to 1.2% in the long-run.

What are the implications for policymakers? Is a monetary policy response called for when exchange rates move? The most commonly advanced rationale for such responses is that the exchange rate changes alter inflationary pressures, which should be offset. This is particularly important in the United Kingdom, as it could imply breaching the Government's inflation target. The aim of any monetary policy response should then be to prevent the exchange rate movement being built into wage setting and pricing behaviour – eliminating the "second round" effects. It should not aim to offset the direct ("first round") effects,[30] which shift the price level and so only affect recorded inflation for a limited period.[31]

In deciding the appropriate *direction* and *magnitude* of any policy response the authorities should, of course, recognise that the direction and magnitude of the price changes associated with an exchange rate movement depend on its source. Unfortunately, identifying the type of shock that generated a particular exchange rate as it happens is very difficult. This could lead to incorrect policy responses. Our finding that past sterling depreciations have largely been associated with small falls in relative prices suggests that depreciations should, if anything, induce small official interest rate reductions. But we have also shown that past sterling fluctuations have not constituted a major channel through which inflationary pressures are transmitted. This suggests that the optimal policy response is to leave interest rates unchanged.

But these conclusions are necessarily provisional because: (a) the above are average results, and will not necessarily apply to every exchange rate movement; (b) they are based upon past relationships that will not necessarily hold in the future – a large potential Lucas critique; and (c) endogenous monetary policy *responses* may already be included in the results. Unfortunately, there are ambiguities about where monetary policy shows up in the model. Clarida and Gali (op cit) allocated monetary policy shocks to LM shocks. This may be motivated by the textbook descriptions of monetary policy in terms of monetary aggregate shifts and the traditional description of monetary policy as a nominal perturbation. But there are several arguments for including monetary policy in IS shocks. First, monetary policy actually operates through interest rates, which then affect domestic demand. Second, Eichenbaum and Evans (1993) demonstrated that monetary policy shocks have long-run real exchange rate effects. Both these are characteristics of IS shocks. Importantly, IS shocks remain unambiguously real phenomena even if monetary policy is included in them; in our framework monetary policy only affects domestic demand if it moves *real* interest rate differentials.[32] These ambiguities reflect the fact that our framework is not intended to identify monetary policy shocks, which the literature as a whole has difficulty doing.[33]

The dominance of real shocks as determinants of sterling exchange rate movements makes our results most consistent with the Stockman (op cit) equilibrium exchange rate theory. However, we have also uncovered evidence of substantial price stickiness. Yet this has not translated into LM shocks constituting major sources of sterling real exchange rate movements – the

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29 We thus omit the UK-US from the AS shock analysis and UK-France from the IS shock analysis.

30 Our empirical framework, however, is incapable of separating out the first round and second round effects.

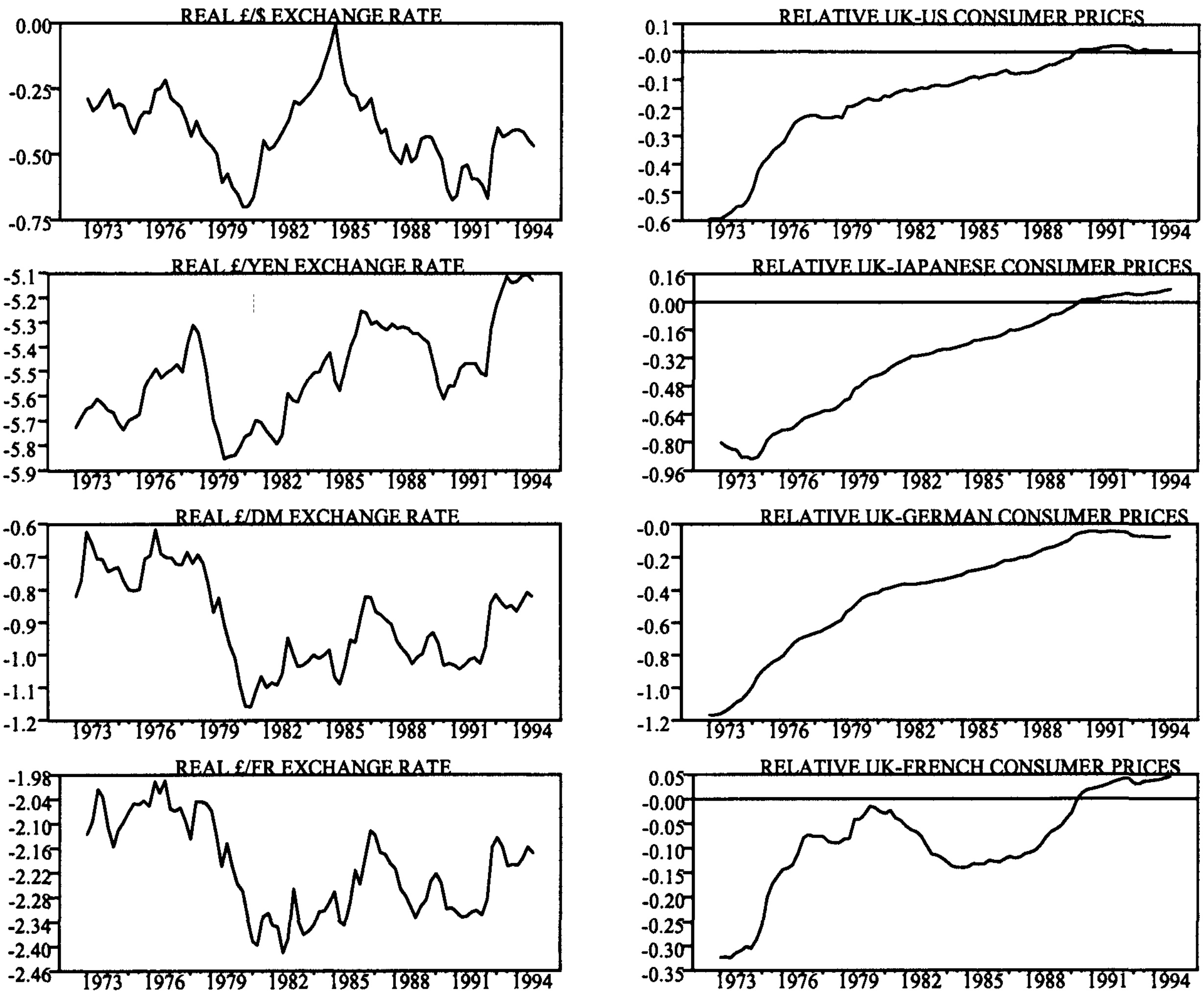
31 Twelve months if the price level shifts immediately.

32 See equation 1 of Appendix A. Sluggish price expectations are obviously required for this to hold.

33 See Rudebusch (1996) for a critique of VAR approaches. SVAR papers by *inter alia* Gerlach and Smets (1995) and Roubini and Kim (1995) attempt to directly identify monetary policy shocks.

disequilibrium view. This suggests that either LM shocks were less prevalent than real shocks over the floating exchange rate period or that they had a lower variance.

Figure 7
Real exchange rates and relative prices



4. Sub-period analysis

How do the SVARs rationalise the sterling real exchange rate and UK relative price movements that occurred (Figure 7) over the sample period? We use historical decompositions (HDs) to plot separately the historic paths that the endogenous variables would have followed in response to each of the structural shocks. This allows us to determine the importance of each of the shocks in exchange rate and price developments over *historic episodes*.[34] We simply examine how closely the endogenous variable movements due to each of the shocks (the light lines in Figures 8 to 15)

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34 This contrasts with the *full sample* FEVD results.

Figure 8
Historical decomposition £/$ exchange rate

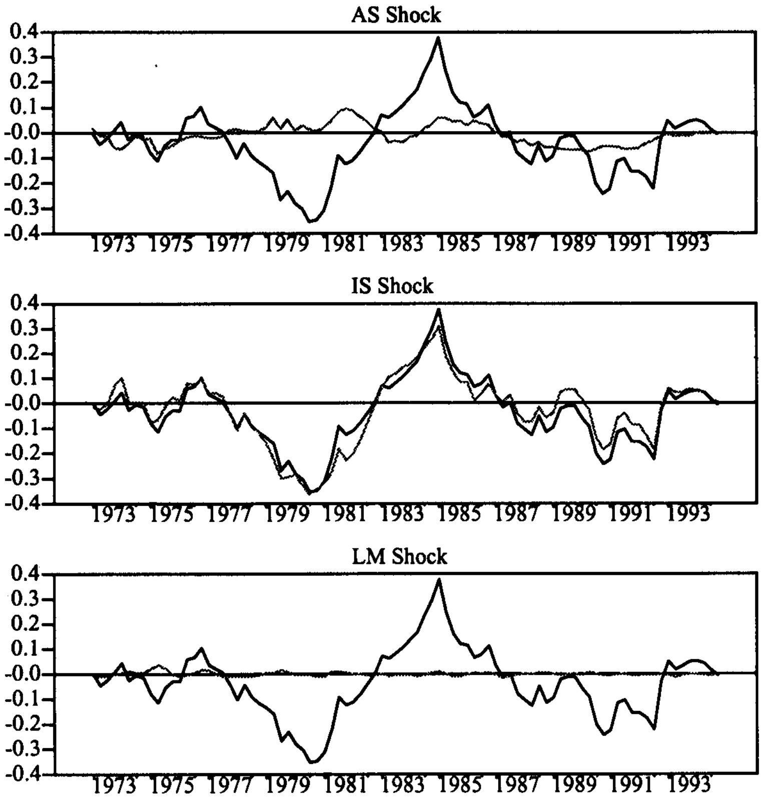


Figure 9
Historical decomposition £/Yen real exchange rate

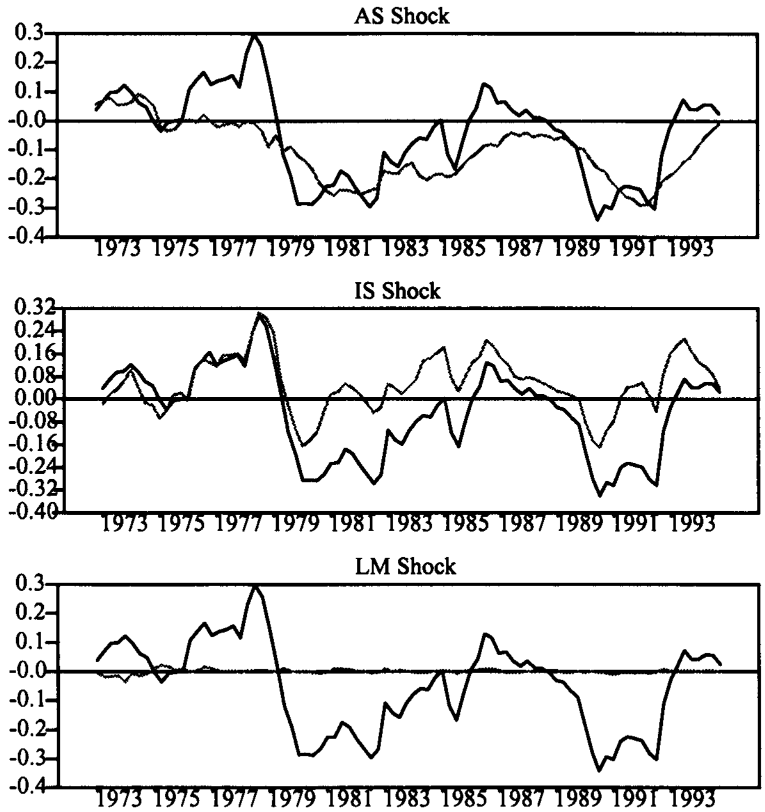


Figure10
Historical decomposition £/DM exchange rate

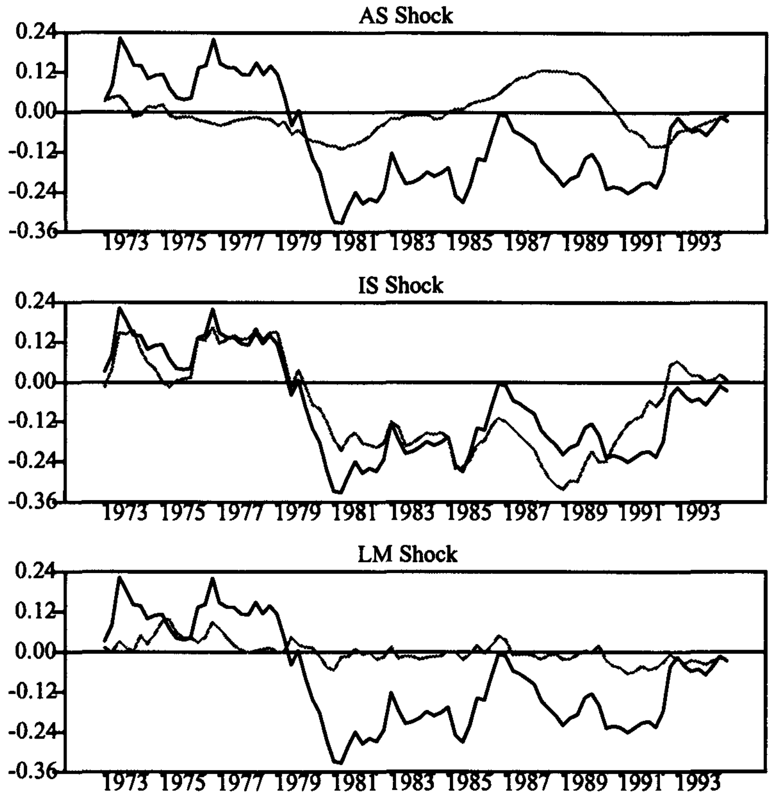


Figure 11
Historical decomposition £/FFr real exchange rate

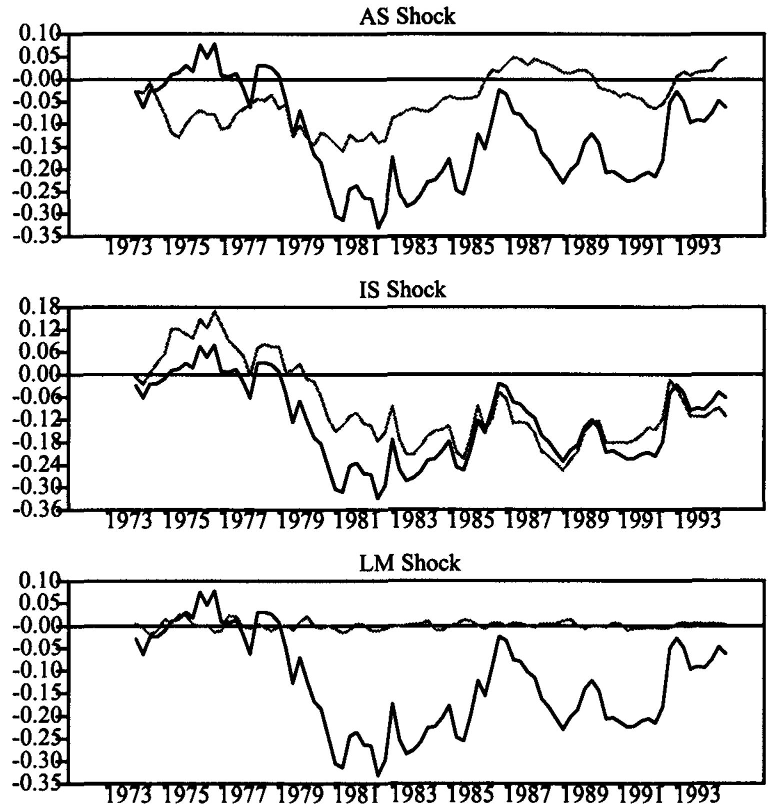


Figure 12
Historical decomposition of UK-US prices

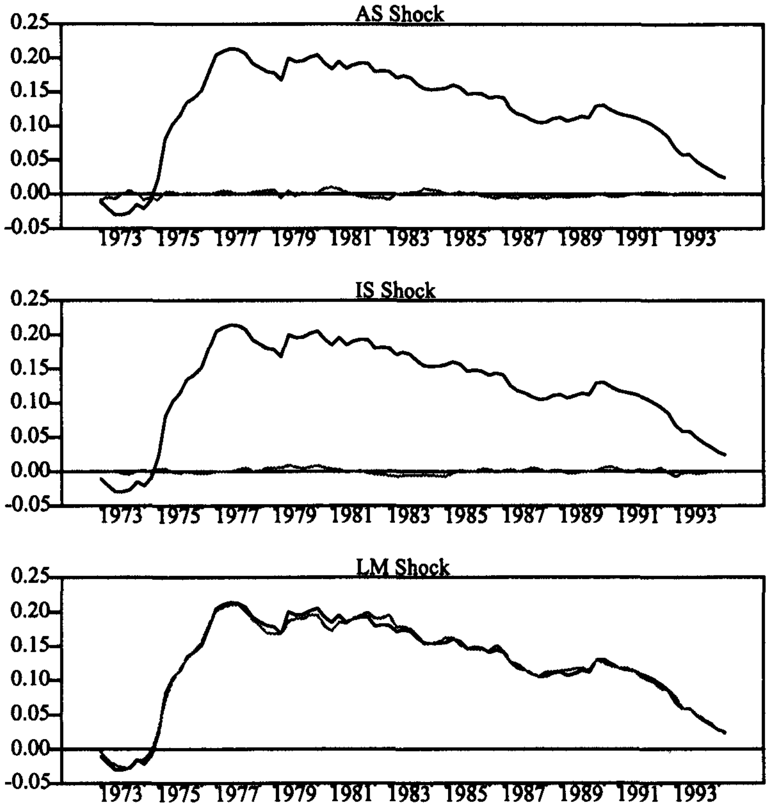


Figure 13
Historical decomposition of UK-Japanese prices

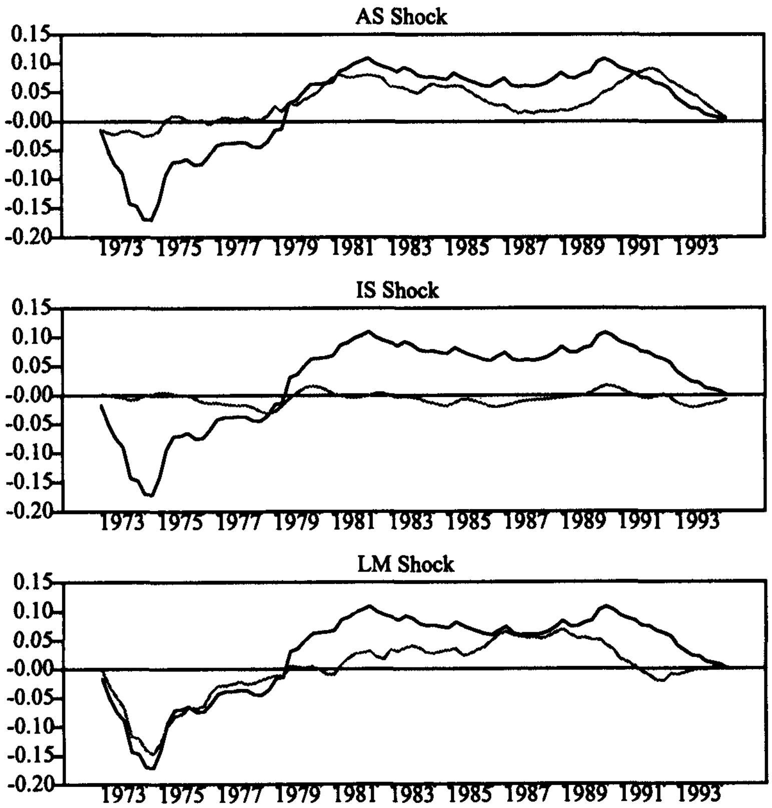


Figure 14
Historical decomposition of UK-German prices

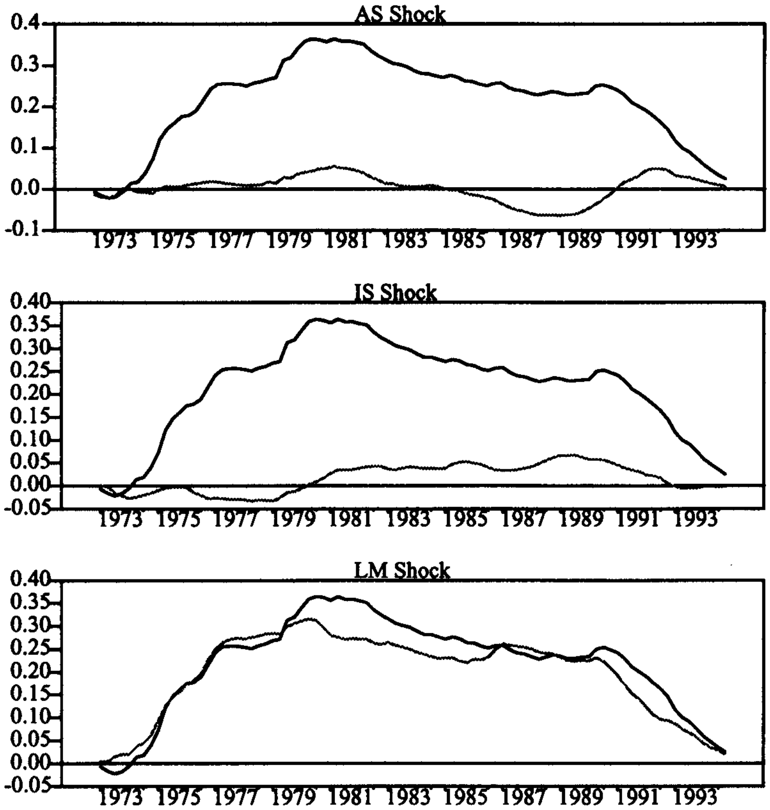


Figure 15
Historical decomposition of UK-French prices

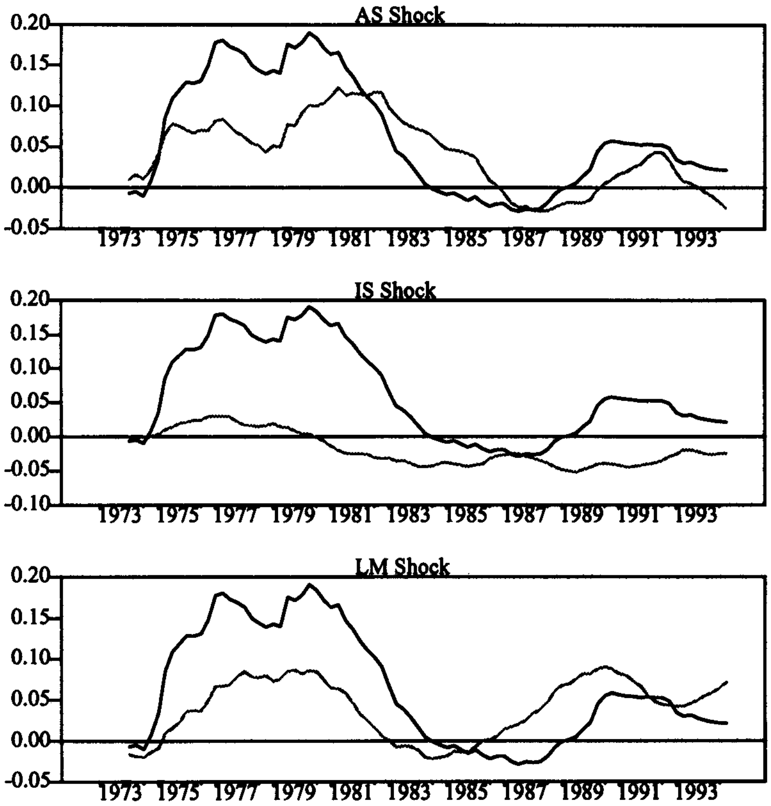
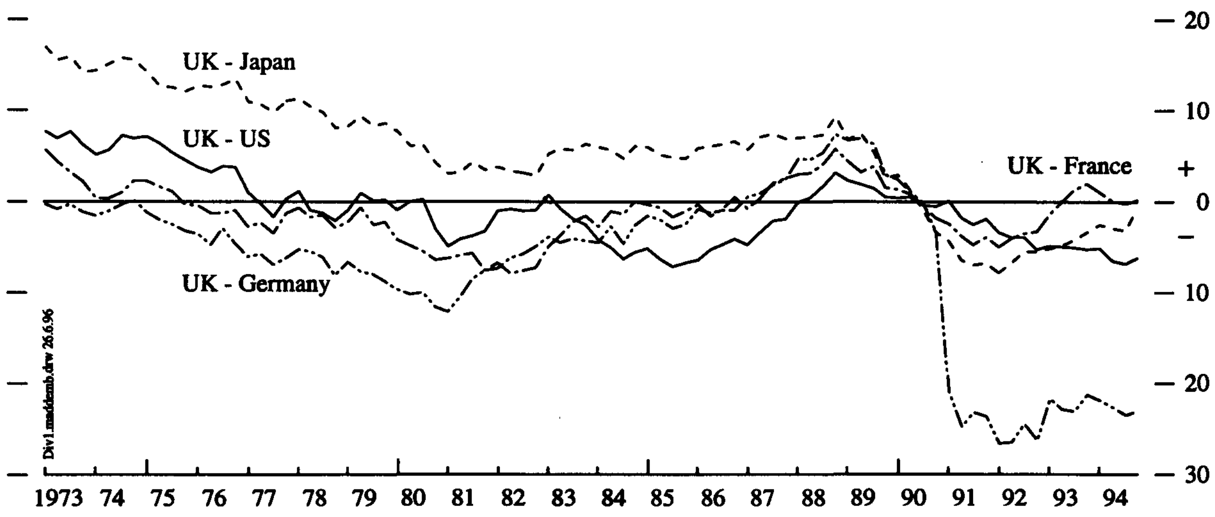


Figure 16

UK – overseas relative domestic demand developments*



* UK domestic demand index (1990 = 100) minus overseas equivalent. Increases (decreases) represent positive (negative) relative demand shocks.

correspond to the actual movements (the dark lines).[35,36] But can these predictions be linked to *observed* economic developments? This is an important cross-check of the economic content of the results. We use relative domestic demand as the equivalent to IS shocks (Figure 16), relative productivity developments[37] as the AS shock measure (Figure 17) and relative broad[38] money growth rates for the LM shocks (Figure 18). We find a high correspondence between these observable developments and the SVARs' predictions in our examination of 1990s exchange rate and price movements. Moreover, this correspondence is also apparent throughout much of the earlier period (not reported to conserve space).

Figure 16 indicates that relative domestic demand shifted away from the UK in the 1990s. The HDs indicate that these negative IS shocks played a large role in the sharp post-1992 real sterling depreciations, especially of the £/$ rate. This ties in with the large role that IS shocks played in sterling movements over whole sample (FEVD results).

The improvement in UK relative productivity, apparent in the 1980s, accelerated in the 1990s (Figure 17). The origin of these positive AS shocks varies between country pairs. The negative short term effects of German reunification and the bursting of the Japanese asset price bubble are likely candidates in the German and Japanese systems. The HDs indicate that these positive AS shocks also played a large role in the post-1992 real sterling *depreciations*. And the neglible role of

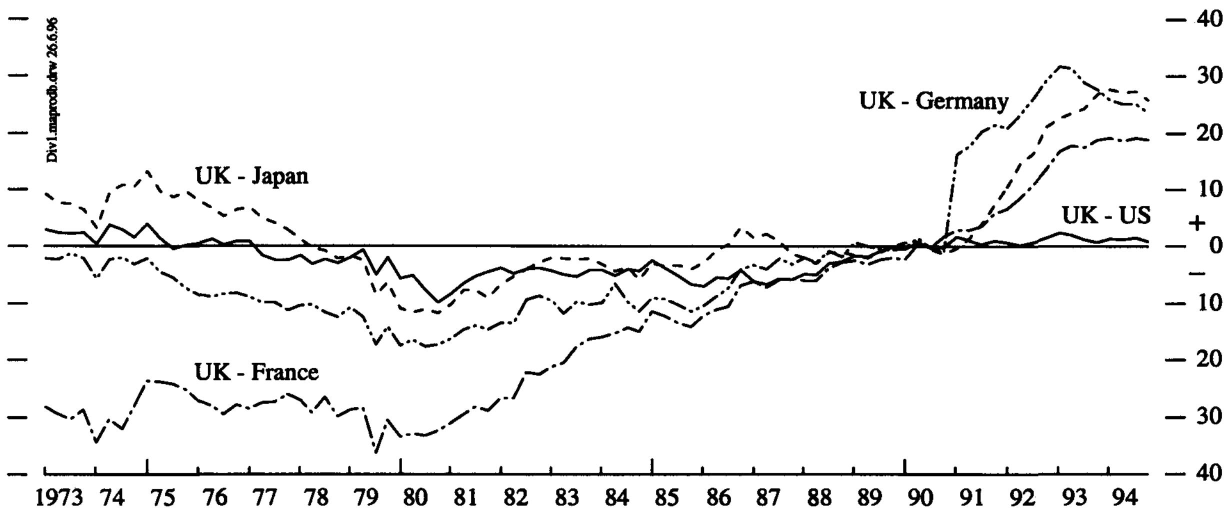
35 The actual path (dark line) with which we compare the decompositions is that which was forecast by the structural VAR model on the basis of a few initial periods of shocks – the "base projection". Endogenous variable movements in excess of this base projection constitute the "news" occurring after the few initial periods. This news must obviously be due to realisations of the three structural shocks after the few initial periods of shocks.

36 Evans and Lothian (op cit) offer the alternative of testing the significance of the constructed path as a determinant of the actual movements over sub-periods. De Arcangelis (1995) implements a similar procedure.

37 As measured by manufacturing output/industrial production per head of employment in manufacturing.

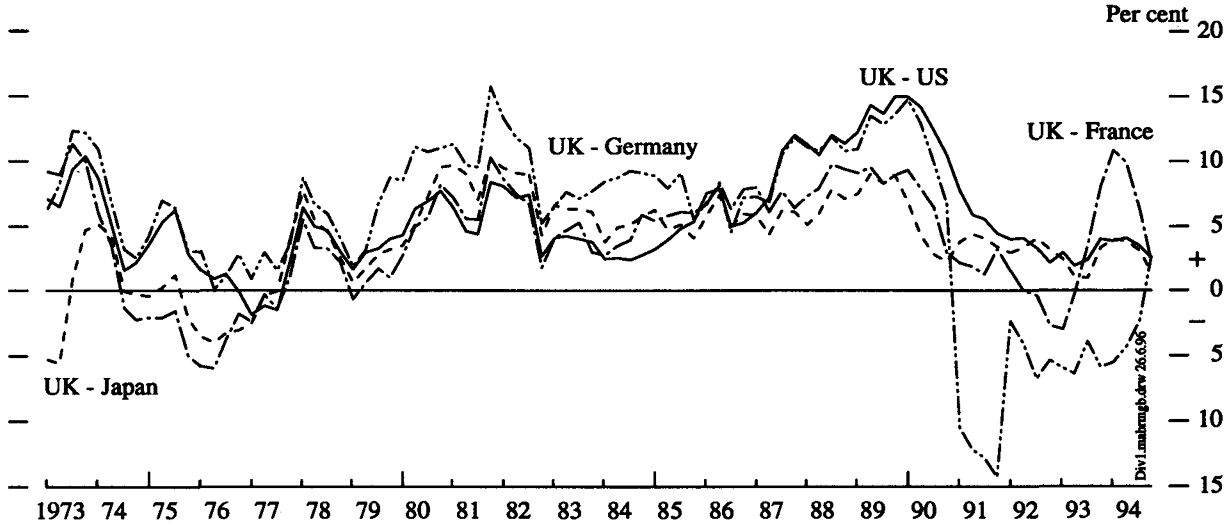
38 Using narrow money aggregates produced similar results.

Figure 17
UK – overseas relative productivity developments*



* UK minus overseas manufacturing output or industrial production per head of employment in manufacturing. Increases (decreases) represent positive (negative) relative supply shocks.

Figure 18
UK – overseas relative broad money[1] growth[2] developments



1 Measures used: UK M4, US M3, Japanese M2 + CDs, German M3 and French M3.
2 UK M4 four-quarter growth rate minus overseas equivalent. Increases (decreases) represent positive (negative) nominal shocks.

AS shocks in the real £/$ depreciation ties in with UK-US productivity differentials being virtually unchanged (around zero) over this period. According to our results, these productivity improvements also played a large role in the flattening of UK relative prices in the 1990s. And their effect again has the intuitive appeal of being least apparent in UK-US price movements.

The September 1992 suspension of sterling's ERM membership might be expected, according to the Mussa (1986) analysis, to constitute a nominal (LM) shock. But the HDs provide no evidence of LM shocks playing a role in the post-1992 real sterling depreciations. This is not, however, surprising. The observed fall in UK relative monetary aggregate growth rates (Figure 18) constitutes a *negative* (less positive) LM shock. These, of course, produce real *appreciations* (slower depreciations), rather than the observed depreciation. LM shocks did, however, contribute to the observed flattening of UK relative prices. And, noticeably, relative money growth rates slowed most at the start of the 1990s – exactly when LM shocks appear to have had their largest price impact.

Conclusion

This paper has presented a number of strong results. The main ones are that IS shocks underlay most of the variance of sterling real and nominal exchange rates and that LM shocks were the main source of UK relative price fluctuations. The most important implications for policymakers are that: (i) sterling depreciations usually have, counter to common perceptions, had benign relative price implications; and (ii) sterling exchange rate movements per se have not constituted a major channel through which exogenous shocks have fed into UK relative prices. Both these points testify to the importance of uncovering the underlying *source* of exchange rate and price movements. We have also argued that the SVAR representations of the data appear to have a high economic content. We believe that our results are sufficiently interesting to merit further investigation in the Lastrapes (op cit), Rogers (op cit) and Evans and Lothian (op cit) frameworks.

Appendix A: Outline of Obstfeld (1985) two-country Dornbusch (1976) model

The following four structural equations make up the Obstfeld (op cit) model:

$$y^d = \eta q_t - \sigma\left(i_t - E_t\left(p_{t+1} - p_t\right)\right) \tag{A1}$$

$$m_t^s - p_t = y_t - \lambda i_t \tag{A2}$$

$$p_t = (1-\theta)E_{t-1}p_t^* + \theta p_t^* \tag{A3}$$

$$i_t = E_t\left(s_{t+1} - s_t\right) \tag{A4}$$

The open economy IS relationship (A1) states that relative output demand (y^d) rises with: (i) real exchange rate (q_t) increases (depreciations);[39] (ii) narrowings of the real interest differential in favour of the home country;[40] (iii) rises in all other exogenous changes to relative domestic absorption (d_t) such as government expenditure and home/foreign goods taste shifts.

The money market equilibria condition (LM curve) (A2) specifies real relative money demand as a positive function of relative output and a negative function of nominal interest rate differentials. The price setting rule (A3) specifies prices in period t as being set as an average of the *output* market clearing price that was expected in t-1 to prevail in period t ($E_{t-1}p_t^*$) and the price that would actually clear the output market in period t (p_t^*). The θ parameter determines the degree of price flexibility, full flexibility holding when $\theta = 1$. Finally (A4) represents a UIP condition linking *nominal* interest rate differentials to *expected* nominal exchange rate changes:

The shocks are introduced by specifying the following stochastic processes for the exogenous variables in equations (A1) to (A3). We assume that the AS (z_t) and LM shocks (v_t) follow simple random walks, being solely permanent in nature. But relative IS (δ_t) shocks have both permanent and transitory components, the latter of which is offset in the following period, that is:

$$\begin{aligned} y_t^s &= y_{t-1}^s + z_t \\ d_t &= d_{t-1} + \delta_t - \gamma\delta_{t-1} \\ m_t &= m_{t-1} + v_t \end{aligned} \tag{A5}$$

The long-run model solution, presented in equations (A6) to (A9), occurs when prices become perfectly flexible and rational expectations hold. Relative output is entirely determined by AS shocks[41] – a vertical long-run supply curve. The absence of LM shocks from (A6) represents money neutrality.

$$y_t^* = y_{t-1}^s + z_t \tag{A6}$$

$$q_t^* = \left(y_t^s - d_t\right)/\left(\eta + (\eta+\sigma)\right)^{-1} \sigma\gamma\delta_t \tag{A7}$$

$$p_t^* = -y_t^s + \lambda(1+\lambda)^{-1}(\eta+\sigma)^{-1}\gamma\delta_t + m_t \tag{A8}$$

39 Demand switches towards home goods as they become more competitive.

40 Reflecting the effect on interest sensitive aggregate demand components such as investment.

41 The $C_{12}(1) = C_{13}(1) = 0$ restrictions outlined in appendix B.

$$s_t^* = y_t^s(1-\eta)\eta^{-1} - d_t\eta^{-1} + \left[\eta(\eta+\sigma)^{-1}\sigma + \lambda(1+\lambda)^{-1}(\eta+\sigma)^{-1}\right]\gamma\delta_t + m_t \tag{A9}$$

The long-run real exchange rate expression (A7) is obtained by substituting the stochastic processes for AS and IS shocks into the IS equation and solving for q_t^*. Positive AS shocks produce long-run real *depreciations* (rises) – an improvement in competitiveness is required to stimulate demand for the extra output supply generated by the AS shock. Conversely, the real exchange rate *appreciates* (falls) following positive IS shocks. But the market's discounting of the partial reversal of the IS shock in the following period, represented by the coefficient on the temporary component of the IS shock (γ), offsets this appreciation. This means that the real appreciation will only be permanent to the extent that the IS shock is permanent. The main text outlines the economics of this result. Finally, LM shocks have no long-run real exchange rate effect;[42] we show below that the associated relative price and nominal exchange rate responses exactly offset each other.

Inverting the LM curve produces the long run price expression (A8). Positive AS shocks reduce relative prices, by shifting the (vertical) AS curve to the right. Positive LM shocks and the temporary component of positive relative IS shocks ($\gamma\delta_t$) both raise relative prices, the former equiproportionately, by shifting the AD curve up the vertical AS curve. The permanent component of IS shocks has no long-run effect on prices. The main text again outlines the intuition of this result.

Expression (A9) demonstrates that only LM shocks have unambiguous long-run *nominal* exchange rate effects. In particular, positive LM shocks produce equiproportionate nominal depreciations in the long-run. The indeterminacy of the long-run responses to IS and AS shocks is due to the their real exchange rate and price effects working in opposite directions. But the main text outlines why in general we expect positive AS (IS) shocks to produce long-run nominal depreciations (appreciations).

In the short-run, when prices are sticky, all shocks potentially affect all endogenous variables. Equations (A10) to (A13) represent the short-run solution. The short-run relative price expression (A10), obtained by substituting (A8) into (A3), illustrates that higher price stickiness (decreases in θ) reduces the short run price effect of each of the shocks below their long-run effects.

$$p_t = \theta p_t^* - (1-\theta)(v_1 - z_t + \alpha\gamma\delta_t) \tag{A10}$$

$$q_t = q_t^* + v(1-\theta)(v_t - z_t + \alpha\gamma\delta_t) \tag{A11}$$

$$\begin{aligned} s_t = {} & y_t^s(1-\eta\theta)\eta^{-1} - d_t\eta^{-1} + (v(1-\theta)-(1-\theta))(v_t - z_t) + \theta m_t \\ & + \left[(\eta(\eta+\sigma))^{-1} + \theta\lambda(1+\lambda)^{-1}(\eta+\sigma)^{-1} - v(1-\theta)\right]\gamma\delta_t \end{aligned} \tag{A12}$$

$$y_t = y_t^s + (\eta+\sigma)v(1-\theta)(v_t - z_t + \alpha\gamma\delta_t) \tag{A13}$$

The short-run real exchange rate expression (A11) is obtained by substituting (A1) and (A4) into (A2) and using (A10) to represent the difference between actual and market clearing price levels.[43] The positive coefficient on v_t illustrates the usual result that positive LM shocks *depreciate* the real exchange rate when prices are sticky. The negative coefficient on z_t shows that price stickiness means that the real exchange rate will undershoot its long-run appreciation following positive AS shocks. Likewise the positive coefficient on $\gamma\delta_t$ illustrates that the real exchange rate

42 The $C_{23}(1) = 0$ restriction of appendix B.

43 Where $v=(1+\lambda)(\lambda+\sigma+\eta)$-1.

undershoots its long-run depreciation following positive IS shocks. Again the extent of this undershoot is related solely to the temporary component of the IS shock ($\gamma\delta_t$)

Equation (A12) presents the short run nominal exchange rate expression. Clarida and Gali (op cit) show that LM shocks produce short run *nominal* exchange rate overshooting if $(1-\sigma-\eta)>0$. And this condition implies short-run nominal exchange rate undershooting following AS and IS shocks.

Finally the short-run relative output expression (A13) is obtained by inserting the sticky price real exchange rate expression (A11) into (A1) and solving for y_t. Relative output is *demand* determined in the short-run, with positive LM shocks (v_t) and the *temporary* component of positive IS shocks ($\gamma\delta_t$) raising relative output. The negative coefficient on zt demonstrates that price stickiness reduces the output effect of AS shocks.

Appendix B: The Blanchard and Quah (1989) structural VAR identification method

The structural model formulates movements of endogenous variables (y_t – relative output, the real exchange rate and relative prices in our case) as a moving average of past *structural* shocks (e_t):

$$\begin{aligned} y_t &= C(L)e_t \\ \mathrm{Var}(e) &= I \end{aligned} \tag{B1}$$

Where $C(L)=\begin{bmatrix} C(L)_{11}\,C(L)_{12}\,C(L)_{13} \\ C(L)_{21}\,C(L)_{22}\,C(L)_{23} \\ C(L)_{31}\,C(L)_{32}\,C(L)_{33} \end{bmatrix}$ and $e_t=\left[z_t\delta_t v_t\right]$

z_t represents the AS shocks, δ_t the IS shocks and v_t the LM shocks. We first estimate the VAR (in first differences):

$$\begin{aligned} A(L)y_t &= \varepsilon_t \\ \mathrm{Var}(\varepsilon_t) &= \Omega \end{aligned} \tag{B2}$$

where A(0)=*I* and ε_t is the vector of *reduced form* residuals. Inverting (B2)[44] produces the moving average representation:

$$y_t = A(L)^{-1}\varepsilon_t \tag{B3}$$

To move from (B3) to (B1), we first assume that a non-singular matrix *S* exists that links the structural shocks (e_t) and the reduced-form disturbances (ε_t) i.e. $\varepsilon_t = Se_t$. Comparing (B3) and (B1) reveals that $C_0 = S$. It is also clear that :

$$C_0 C_0' = \Omega \tag{B4}$$

44 We assume that the MA representation is invertible. See Lippi and Reichlin (1993) and Blanchard and Quah (1993) for discussions of the consequences of non-invertibility.

To identify C_0, the key to the procedure, we need to impose n^2 restrictions are imposed (n is the number of variables in the system, three in our case). The usual assumptions of orthogonality and unit variance of the structural shocks (e_t) provides $n(n+1)/2$ (six) of these restrictions. This means that (B4) is a system of $n(n+1)/2$ (six) equations in n^2 (nine) unknowns. Thus $n(n-1)/2$ (three) further restrictions are required to achieve (exact) identification. We follow Blanchard and Quah (op cit) in employing long-run *theory*-based restrictions zero to complete the identification.

We denote the *sum* of the structural MA matrices[45] by $C(1)$. The restriction that shock j has zero long-run effect on the *level* of endogenous variable i requires the restriction $C_{ij}(1)=0$ to be imposed. We follow the Clarida and Gali (op cit) formulation of the three required long-run restrictions. First, the shock which we label as "IS" (δt,) has zero long-run relative output effects: $C_{12}(1)=0$. Second, the shock we label as "LM" (v_t) also has zero long-run relative output effects: $C_{13}(1)=0$. Long-run relative output is thus entirely determined by the first shock, which we label as "AS"(z_t) – a vertical long-run aggregate supply curve. Finally, LM shocks are constrained to have zero long-run effect on the real exchange rate: $C_{23}(1) = 0$. These restrictions mean that, as in Blanchard and Quah's (1989) bivariate case, the $C(1)$ matrix is *lower triangular.*

The procedure to obtain an estimate of C_0 parallels that outlined in Blanchard and Quah (op cit). First calculate:

$$(I - A(1))^{-1}\Omega\left((I - A(1))^{-1}\right)' \quad \text{(B5)}$$

It is easily shown that $C(1)$ obeys the following equality:

$$(I - A(1))^{-1}\Omega\left((I - A(1))^{-1}\right)' = C(1)C(1)' \quad \text{(B6)}$$

But we can also compute the *lower triangular* Choleski decomposition of (B5), which we denote by H. As $C(1)$ is also lower triangular, it may clearly be equated to H. Combined with the fact that $(I-A(1))$-1 = $C(1)C_0$, we obtain a C_0 as follows:

$$C_0 = (I - A(1))H \quad \text{(B7)}$$

From (B2) and (B4) it is clear that:

$$C_j = (I - A_j)^{-1} C_0 \quad \text{(B8)}$$

showing that identifying C_0 allows the computation of the dynamic responses of the variables to the structural shocks. The time series of structural shocks are also easily obtained ($e_t = C_0^{-1}\varepsilon_t$). And the orthogonality and unit variance of the structural shocks makes it simple to compute the structural forecast error variance decompositions. Finally, historical decompositions may also be straightforwardly obtained.

45 That is $C(1) = C_0 + C_1 + C_2 + \ldots.. C_\eta + \ldots..$

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Comments on paper by M.S. Astley and A. Garratt by Frank Smets (BIS)

This paper analyses the sources of sterling real and nominal exchange rate fluctuations using a structural VAR model proposed in Clarida and Gali (1994). The paper is well-motivated. Knowledge about what drives the exchange rate is important for monetary policy makers as it may determine the inflationary consequences of an exchange rate change and therefore the appropriate policy response. The main finding of the paper is that most of the nominal and real exchange rate movements are caused by real demand shocks, which have only limited effects on relative prices. The tentative policy conclusions the authors draw from this is that the optimal policy response may be to leave interest rates unchanged in the face of exchange rate changes. My comments will be in two parts. In the first part I deal with the identification problem in structural VARs and how this may have affected the results presented in the paper. The second part deals with the policy implications the authors draw from their analysis.

The goal of structural or identified VAR analysis is to interpret some of the correlations in the data in terms of a limited number of structural shocks. In the spirit of Sims (1980) only a minimum number of assumptions is used to identify these structural shocks. One problem with this approach is that in many cases there is no obvious one to one relationship between the kind of shocks one wants to examine and the identification scheme. This may be problematic because differences in identifying assumptions are known to have nontrivial effects on the impulse responses and the historical and variance decompositions. This uncertainty puts the burden of the proof with respect to the structural interpretation on the SVAR practitioners. The authors do a good job in making their case. They follow Clarida and Gali (1994) in motivating the long-run identifying assumptions on the bases of a standard open economy AS-AD model whereby only supply shocks have long-run effects on output and nominal (LM) shocks are neutral in the long run. They show that the estimated impulse responses to these shocks by and large satisfy the over-identifying implications of the model and they try to use historical decompositions to convince the reader that the estimated structural shocks also correspond to plausible actual events. Nevertheless, in what follows I will argue that the model may be misspecified in a way which could affect the main results and that therefore some caution is necessary in interpreting the results.

Let me first comment on the plausibility of the long-run identifying assumptions, i.e. a long-run vertical supply curve and long-run money neutrality, that are used to identify the three fundamental shocks (AS, IS and LM). The authors claim "the strength of the restrictions is their generality and uncontentious nature". While I would like to believe in these long-run assumptions, they are not that uncontentious. With respect to the first assumption, I know at least one SVAR study (Bayoumi and Thomas (1994)) which assumes exactly the opposite long-run identifying assumption to distinguish supply from demand shocks. As Bayoumi and Thomas wanted to compare factor market integration between the states in the United States and countries in Europe, they had a very good reason for not imposing a long run vertical supply curve. Factor market integration would tend to make the long-run supply curve upward-sloping. Fortunately for the authors, Bayoumi and Thomas find that the supply curve in European countries is almost vertical, in contrast to the supply curve in the US states, probably reflecting differences in factor market integration.

With respect to the second assumption of money neutrality, the authors themselves point to the fact that there is quite a lot of evidence that monetary policy shocks have real exchange rate effects even in the medium to long run (see Section 3). To the extent that this misspecification implies an underestimation of the exchange rate effects of nominal (LM) shocks, some of the sharp results about the near dichotomy between exchange rate changes and relative price changes may disappear. Another way of looking at these issues is from the perspective of recent research on long-run PPP. More and more papers (e.g. Oh (1996)) are able to reject the hypothesis of a unit root in the real exchange rate using more powerful econometric techniques or longer data. If indeed long-run PPP holds, then the assumptions in the model would again imply a serious misspecification and would tend to underestimate the exchange rate effects of nominal shocks.[46]

Even if the structural shocks one wants to analyse satisfy the identifying assumptions, one should realise that other shocks may also do so. In that case the impulse responses one estimates are an amalgam of the effects of each of these shocks, leading to a misspecification of the impulse responses, variance decompositions, etc. This will in particular be a problem in small-scale VARs where the number of identified shocks is inevitably limited. In what follows I consider two examples which may affect the conclusions drawn from the paper.

First, consider the estimated LM shocks. These shocks are not only a mixture of money supply and money demand shocks, they may also incorporate temporary real demand shocks, which similarly have no long run effect on real output and the real exchange rate. The reason why this is important is that while a temporary real demand shock has a similar short run effect on output and prices as an increase in the money supply or a reduction in money demand, it has a different impact on the exchange rate. A positive temporary demand shock will most likely lead to an appreciation of the exchange rate, while an expansionary monetary policy shock will initially lead to a depreciation. If the so-called LM shocks are a mixture of both shocks, then this will tend to bias downward the effect on the exchange rate, which, again, may explain the main result in this paper.[47]

Second, consider the IS shocks. One of the surprising results in the Astley-Garratt paper is that these shocks which are, for example, meant to capture permanent increases in government spending have very limited output and price effects. How can this be? One possible interpretation is that these shocks do not primarily reflect aggregate demand shocks but rather permanent shocks to the risk premium required on sterling investments. One could easily extend the theoretical model in the paper to incorporate such shocks and find that a permanent rise in the required risk premium would lead to a permanent real exchange rate depreciation. Moreover, if the central bank allows the real interest rate to immediately adjust to this shock, then one would also find that the effects on output and prices are very limited, suggesting that the so-called IS shocks could be interpreted as risk premium shocks. This brings me to the policy interpretation of the results.

In Section 3 the authors state "... we have shown that past sterling fluctuations have not constituted a major channel through which inflationary pressures are transmitted. This suggests that the optimal policy response is to leave interest rates unchanged". Above we have argued that this main result may be due to various identification problems. However, even if it holds, it would not necessarily justify the policy implication. The reason for this is that the estimated impulse response functions incorporate the endogenous reaction of the monetary authorities to the underlying shock. Take, for example, the case in which the estimated IS shocks would partly represent risk premium shocks. As mentioned above a likely reason why such shocks may not turn into relative output and price movements is that the monetary authorities lean against them by changing the policy-controlled interest rates. This would, for example, be the case if the central bank targets some form of monetary conditions index as currently in Canada. An extension of the Clarida-Gali model which includes the short-term interest rate differential does indeed show that the interest rate differential rises sharply in response to an expansionary IS shock, presumably reducing the inflationary effects. Clearly, following the authors' policy advice of leaving interest rates unchanged could very well result in relative price effects, which were to be avoided in the first place.

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46 As an aside I should mention that using a limited number of lags with long-run restrictions, will tend to reduce the importance of temporary shocks in the variance decomposition. For example, using four lags instead of one in the sterling/DM model one increases the contribution of the LM shocks to the real exchange rate forecast error variance from 8% to 40%. Such a dramatic increase in the contribution of nominal shocks may change the conclusions of the paper.

47 Indeed, some attempts to distinguish between temporary demand shocks and monetary policy shocks by including the short-term interest rate differential while maintaining the long-run restrictions à la Clarida and Gali, raised the joint importance of these shocks in explaining real and nominal exchange rate changes from close to zero to over 50% in the short term.