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SOURCES OF PURCHASING POWER DISPARITIES BETWEEN THE G3-ECONOMIES

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ABSTRACT

Recent theoretical and empirical research in international macroeconomics has rediscovered the problem of purchasing power parity (PPP). Empirically, PPP is a bad approximation of both the short-term and medium-term properties of the data. Economists have had difficulties in explaining the persistent misalignments of real exchange rates, but new empirical research by Clarida and Galí (1995) suggests that much of these real exchange rate movements are due to relative demand shocks. The present paper challenges this view by using an extended version of their structural vector autoregressive (SVAR) model in order to identify a larger number of real shocks (labour supply, productivity and aggregate demand) and nominal shocks (money demand and money supply). It is found that whilst some of their results go through in our extended framework, there is serious doubt with respect to the appropriateness of labelling those shocks which drive real exchange rates as aggregate demand disturbances.

JEL classification: F0, F3

Keywords: purchasing power parity, real exchange rates, shocks, structural vector autoregression, impulse response functions, variance decompositions

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1. Introduction

In a recent survey of the purchasing power parity (PPP) puzzle Rogoff (1996) points out that most explanations of short-term nominal exchange rate volatility suggest a large role for monetary and financial shocks as opposed to real shocks to technology, productivity or preferences, which typically are considered to not be volatile enough to explain this phenomenon. If nominal shocks dominate short-term nominal exchange rate movements, they must also account for most of the short-run real exchange rate changes in the face of short-term sticky prices and wages. But prices and wages will ultimately adjust in the long-run. Why then do deviations from PPP die out at such a low rate (of 15 percent per year)? The PPP puzzle suggests that some real disturbances, rather than nominal shocks, must be important for real exchange rates in the medium-run to long-run. Economists, unfortunately, have not yet been successful in isolating the important real disturbances underlying long-run real exchange rate movements. But such quantitative research is now beginning to emerge. Rogoff (1996) views research by Clarida and Galí (1994, 1995), and Rogers (1995), which employs structural vector autoregressions (SVARs) as being very promising in this context. However, this research is still at an early stage. The present paper reviews and extends this literature by quantifying a larger number of shocks, which both in the short-run and in the long-run appear to drive real exchange rates in G3-countries after the collapse of the Bretton Woods system. An interesting issue thereby is which type of shocks has dominated real exchange rate movements at what frequency. Clarida and Galí (1996) suggest that for the U.S. dollar real exchange rates of the G3-economies aggregate demand shocks play a key role in the long-run; monetary shocks have primarily short-run effects which die out slowly (with a half-life of 16 quarters). They also find that supply shocks play virtually no role for real exchange rate movements over any time horizon. The present paper reconsiders this evidence in an extended version of the Clarida and Galí (1995) model by splitting supply shocks into labour supply and productivity shocks, and by viewing monetary shocks as being composed of money demand and money supply shocks.

What prior judgement does economic theory suggest with respect to the relative importance of real versus nominal shocks in this context? Labour supply shocks or aggregate supply shocks, such as changes in oil prices, raise output, shift the terms of trade and thereby persistently move real exchange rates. Relative productivity shocks alter competitiveness and hence have similar long-run real exchange rate effects. The increased importance of real shocks after the 1970's may explain why real exchange rate volatility has increased and this in turn may explain the shift to flexible rather than fixed exchange rates as the best policy response to the changing state of the world economy. To evaluate the relevance of this proposition, a quantitative assessment is required. In order to identify the major forces behind real exchange rate movements we look at the joint behaviour of real exchange rate changes, output and employment growth differentials, inflation differentials, and money growth differentials. The joint behaviour of these variables is viewed as being driven by five distinct disturbances: labour supply and productivity shocks, aggregate demand shocks, and monetary or financial shocks, such as money demand and money supply disturbances. Based on a simple Mundell-Flemming-Dornbusch IS-LM model[1] we construct and estimate a structural VAR model, and we rely exclusively on long-run theoretical restrictions in order to identify these shocks. The long-run restrictions rest on the long-run neutrality of nominal shocks and the predominant influence of supply shocks on potential output and employment, whilst in the short-run both nominal and real shocks can have real effects due to sluggish price adjustment. Having identified the shocks, we then look at the components of real exchange rate movements due to

[1]On theoretical grounds an intertemporal optimizing approach would clearly be preferable, but to compare our results to those obtained in previous research, we follow this more traditional approach.

these shocks. We also analyse the variance decomposition of real exchange rates over various time horizons in order to determine whether the same factors which drive the short-term volatility of real ex-change rates also determine their medium-term swings and long-run trend movements.

The remainder of the paper is organized as follows: section 2 outlines our theoretical model and derives the rational expectations reduced forms for the short-run under sluggish price adjustment and for the long-run under fully flexible prices. Our empirical results for the G3-economies are presented in section 3. Section 4 concludes.

2. A stochastic rational expectations open economy macro model

This section presents an extended version of the stochastic two-country rational expectations open economy macro model developed by Obstfeld (1985), as presented in Clarida and Galí (1995). The model also draws heavily on papers by Dornbusch (1976), Branson (1979), Flood (1981), Mussa (1982), Shapiro and Watson (1988), Blanchard and Quah (1989), Galí (1993) and Rogers (1995). Both short-run and long-run properties of the model are discussed in detail, and it is found that the model not only reflects most the standard Mundell-Fleming-Dornbusch short-run results when prices adjust sluggishly to various shocks, but it also displays all the long-run properties that typically characterize macroeconomic equilibrium in a more neoclassical framework once prices have adjusted fully to all shocks. Following the usual tradition, all variables except interest rates are in logarithms and represent home relative to foreign levels. For example, $y_t \equiv y_t^h - y_t^f$ represents the logarithm of the output ratio home (y_t^h) and abroad (y_t^f).

The goods market is characterized by a standard output demand function, which displays the real exchange rate ($q_t = s_t - p_t$), the real interest rate differential $\left(i_t - E_t\left(p_{t+1} - p_t\right)\right)$ and the real wage rate $(w_t - p_t)$ as its main arguments:

$$y_t^d = h(s_t - p_t) - s\left(i_t - E_t(p_{t+1} - p_t)\right) + f(w_t - p_t) + d_t\ , \tag{1}$$

and where d_t is a relative demand shock. In contrast to Clarida and Galí (1995) we only allow for a permanent component (e_t^d) of the relative demand shock. In particular, we suppose that the shock to relative demand in period t is given by:

$$d_t = d_{t-1} + e_t^d, \tag{2}$$

where e_t^d is a normally independently distributed (n.i.d.) with zero mean and constant finite variance.

The basic structure of the supply side of the simple open economy macro model follows Shapiro and Watson (1988) in assuming that firms in the long-run produce consumer goods with a Cobb-Douglas technology:

$$y_t^s = A_t + a l_t + (1-a)k_t, \tag{3}$$

where k_t is the log level of the capital stock, l_t is the log level of the labour input, and A_t is the log level of technology. In order to avoid having to incorporate the capital stock in our model we adopt the assumption that the long-run steady state capital-output ratio is constant:

$$k_t = y_t + k, \tag{4}$$

and given by κ. Substituting (4) into (3) and rearranging yields the long-run log level of output:

$$y_t^s = \frac{(1-a)k}{a} + \frac{1}{a}A_t + l_t, \tag{5}$$

where the constant ((1-α)κ/α) will be suppressed below. To capture the dynamics of technology we introduce a stochastic forcing process which reflects the impact of permanent stochastic production technology innovations (e_t^z):

$$A_t = A_{t-1} + e_t^z, \tag{6}$$

where the technology shocks (e_t^z) are assumed to be normally independently distributed with zero mean and constant finite variance.

The demand for labour in each country depends on relative factor costs for labour and is a negative function of the real wage rate. As a result, home relative to foreign labour demand is given by:

$$l_t^d = -ß(w_t - p_t), \tag{7}$$

and is decreasing in the real wage differential. Labour supply, on the other hand is a positive function of the real interest rate differential and the real wage ratio:

$$l_t^s = j\left(i_t - E_t\left(p_{t+1} - p_t\right)\right) + g\left(w_t - p_t\right) + w_t, \tag{8}$$

where w_t represents the stochastic component of the evolution of the labour supply resulting from permanent labour supply shocks (e_t^w):

$$w_t = w_{t-1} + e_t^w, \tag{9}$$

with the labour supply shocks (e_t^w) being assumed to be normally independently distributed with zero mean and constant finite variance.

To introduce some nominal rigidities into the model we adopt a version of the price setting equation that has been studied in open economy macro models by Flood (1981), Mussa (1982), Clarida and Gali (1995), and others:

$$p_t = (1 - q)E_{t-1}p_t^e + qp_t^e. \tag{10}$$

According to this price-setting rule the price level in period t is a weighted average of the market clearing price expected in period t-1 to prevail in period t, $E_{t-1}p_t^e$, and the price which would actually clear the output market in period t, p_t^e. When q=1, prices are fully flexible and output is supply determined. When q=0, prices are fixed and predetermined one period in advance.

The money market of the simple open economy rational expectations model is described by a standard demand for money function, which features relative incomes (y_t) and the nominal interest rate differential (i_t) as its main arguments. To be more specific, we relate the inverse of the relative income velocity of money to movements in the interest rate differential and asymmetric velocity shocks:

$$m_t^d - p_t - y_t = -l i_t + \left(e_t^m - d_t\right), \tag{11}$$

where $e_t^m - d_t$ is the inverse of the relative velocity shock, which has a relative demand shock component d_t and a relative money demand shock component e_t^m. Both shocks are assumed to be normally independently distributed with zero mean and constant finite variance. Interest rates are assumed to be determined by the uncovered interest rate parity condition:

$$, \tag{12}$$

where rp_t represents the risk premium. Such risk premia reflect the fact that domestic and foreign bonds may not be perfect substitutes: in order to induce domestic agents to hold the more risky foreign bonds they have to be granted such a risk premium. In this paper we will follow Clarida and Galí (1995) and the bulk of the literature on the Mundell-Flemming model and exclude such risk premia. However, as Clarida and Galí (1995) point out, our results and identifications would still go through if we model the risk premium as a stationary stochastic process, which itself is a function of our structural shocks.

We close the model by specifying the relative money supplies. We assume that central banks attempt to target a constant money growth rate, which for simplicity is assumed to have a deterministic component that is identical in both countries, and hence the deterministic component of the money growth differential is zero. The relative money supply may thus be captured by a simple stochastic trend:

$$m_t^s = m_{t-1} + e_t^m, \tag{13}$$

with e^m_t as a relative money supply shock, which again is assumed to be normally independently distributed with zero mean and constant finite variance.

Note that the above policy rule strictly only applies under a free float. Modifying the money supply rule to a feedback-rule, in which the central bank responds to contemporaneous shocks in order to stabilize nominal exchange rates or prices will qualitatively alter the behaviour of prices and exchange rates. But since no restrictions are imposed on these variables in our model, this would not alter our basic identification strategy. Thus, to economize on notation we will stick to equation (13) as our monetary policy rule.

2.1 Solving the model

To solve the model, we begin with deriving an expression for the real exchange rate that would prevail in the flexible-price rational expectations equilibrium in which output, employment and the money stock are supply determined. Substituting the equilibrium real wage rate and real interest rate together with the laws of motion for w_t, into (7), the long-run solution for the relative employment level in the flexible-price rational expections equilibrium is given by:

$$l^e_t = l_t = \frac{b}{b+g}\left(w_{t-1} + e^w_t\right), \tag{14}$$

and the corresponding solution for the output ratio is obtained by inserting (6) and (14) into (5):

$$y^e_t = y^s_t = \frac{\left(A_{t-1} + e^z_t\right)}{a} + \frac{b}{b+g}\left(w_{t-1} + e^w_t\right). \tag{15}$$

Note that in the long-run both employment and output are independent of aggregate demand shocks and nominal shocks such as money supply or money demand shocks.

Substituting the equilibrium real wage and real interest rate together with the laws of motion for A_t, d_t, and w_t into (1), solving for q_t^e, and carrying out the conditional expectation projections results in:

$$q_t^e = \frac{1}{h}\left(\frac{\left(A_{t-1} + e_t^z\right)}{a} - \left(d_{t-1} + e_t^d\right)\right) + \frac{s + f}{h\left(b + g\right)}\left(w_{t-1} + e_t^w\right). \tag{16}$$

The flexible-price real exchange rate depreciates in response to both a relative technology shock and a relative labour supply shock. As in Clarida and Galí (1995) the real exchange rate appreciates in response to a relative demand disturbance.

In order to derive an expression for the relative price level p_t^e in the flexible-price rational expectations equilibrium we solve (11) for p_t^e, and using (12) and (13) we obtain:

. (17)

All six shocks influence the relative price level in the flexible-price solution: the relative price level rises equiproportionally in response to the relative money supply shocks and falls in response to relative money demand shocks. Relative prices also decline as a result of a relative supply shock (technology shocks or labour supply shocks), and rise in response to relative demand shocks.

Comparing equations (15) and (16) yields an equation for the nominal exchange rate:

$$s_t^e = \left(m_{t-1} + e_t^m\right) - \frac{(1-h)}{h}\left[\frac{\left(A_{t-1} + e_t^z\right)}{a} - \left(d_{t-1} + e_t^d\right)\right] + \left(\frac{b + f - hb}{h\left(b + g\right)}\right)\left(w_{t-1} + e_t^w\right)_t - \left(\frac{1}{(1 + l)}\right)e_t^m.$$

This is not an independent reduced form solution, but simply the linear combination of the above two reduced forms. It therefore contains no additional information useful for identification. However, it reveals that in the flexible-price solution both money supply shocks and money demand shocks have an identical impact on both the price ratio and the nominal exchange rate. Also notice that without order conditions (i.e. 1-*h*>0) the effect of productivity shocks, labour supply shocks and aggregate demand shocks on the nominal exchange rate is uncertain.

The flexible-rate solution for the ex ante nominal interest rate differential i_t can simply be obtained by carrying out the rational expectation projections of the expected rate of exchange rate change based on the exchange rate equation above:

$$i_t^e = \left(\frac{1}{(1+l)} \right) e_t^m .$$

Inserting this expression into the money demand equation yields the long-run solution for level of real money balances as:

$$, \qquad (18)$$

Real money balances rises in response to relative money demand shocks, whilst money supply shocks have no effect on real money balances in this flexible price solution. Furthermore, real money balances increases in response to relative technology shocks and relative labour supply shocks, whilst relative aggregate demand shocks reduce the demand for real money balances.

The dynamic response of our five key variables to the various shocks in the "long-run" flexible-price solution can be summarized as:

$$\begin{bmatrix} l_t \\ y_t \\ s_t - p_t \\ m_t - p_t \\ p_t \end{bmatrix} = \begin{bmatrix} l_{11} & 0 & 0 & 0 & 0 \\ l_{21} & l_{22} & 0 & 0 & 0 \\ l_{31} & l_{32} & l_{33} & 0 & 0 \\ l_{41} & l_{42} & l_{43} & l_{44} & 0 \\ l_{51} & l_{52} & l_{53} & l_{54} & l_{55} \end{bmatrix} \begin{bmatrix} e_t^w \\ e_t^z \\ e_t^d \\ e_t^{\mathrm{m}} \\ e_t^m \end{bmatrix} . \qquad (19)$$

This matrix of "long-run" multipliers is lower triangular: only the price level is driven by all five shocks, whilst relative employment and output only respond to supply shocks (labour supply and technology shocks) and not to aggregate demand shocks or monetary shocks (money supply or money demand shocks). These monetary shocks only move nominal variables, such as the nominal interest rate differential, the nominal exchange rate and the relative price of output. Monetary shocks therein have identical long-run effects on the nominal exchange rate and relative prices (or wages), which in turn renders the real exchange rate independent of monetary shocks in the long-run. This is not true for demand shifts in favour of domestic goods, which for a given relative supply of goods and labour have to result in a real depreciation if markets are to clear.

Before analyzing the sticky-price equilibrium it is worthwhile mentioning some interesting features of the above five equation model, which could not be analyzed in the context of the three equation model of Clarida and Galí (1995): endogenizing the labour market amounts to endogenizing average labour productivity (y_t/l_t), and this may be used to judge the Balassa (1964) and Samuelson (1964) hypothesis that productivity differentials play a key role in explaining persistent real exchange rate movements.[2] In fact, labour productivity in the long-run solution of our model is driven only by relative technology shocks, and according to the Balassa-Samuelson hypothesis such real shocks should play the central role in accounting for real exchange rate movements. A second interesting aspect of our model relates to the close link between real exchange rate changes and real interest rate differentials. In the long-run solution the ex ante real interest rate differential simply reflects the transitory component of the real exchange rate. In view of the empirical finding that real exchange rates appear to possess a unit root (Campell and Clarida (1987), Meese and Rogoff (1988), Clarida and Galí (1995)), this suggests that most of the long-run movements in real exchange rates must be

[2] Samuelson (1964) and Balassa (1964) actually relate persistent real exchange rate movements to sectoral productivity in a model with traded and non-traded goods sectors. To link this to our approach we refer to Canzoneri, Cumby and Diba (1996), who show that for a wide class of production functions (much less restrictive than Cobb-Douglas) and competitive domestic labour markets one may use average labour productivity to judge the Balassa-Samuelson hypothesis.

attributable to permanent real shocks. This justifies our focus on permanent rather than transitory real shocks.

The short-run sluggish-price-adjustment solution of our model may be derived by viewing quantities as being demand rather than supply determined. By substituting (17) into the price setting rule (10) and carrying out the conditional expectations projection, we derive that the ratio of home to foreign price levels, p_t, is given by:

$$\mathrm{p}_t = \mathrm{p}_t^{e} - (1-q)\left\{ e_t^{m} - \frac{e_t^{z}}{a} - e_t^{d} + \frac{b e_t^{w}}{(b+g)} - \frac{e_t^{m}}{(1+l)} \right\}. \qquad (20)$$

As in the long-run flexible-price solution, the ratio of the price levels in the short-run sluggish-price-adjustment solution is a function of all five shocks. In response to a money supply or aggregate demand shock the price level rises in the short-run, but by less than in the long-run. Furthermore, the price level falls in the sticky-price solution as a result of money demand, aggregate supply or labour supply shocks, again by less than in the flexible-price solution. The degree of "sluggishness" is indexed by (1-*q*).

The real exchange rate solution under partial price adjustment may be obtained by substituting (1) and (12) into (11) and using (20) to obtain:

$$\mathrm{q}_t = \mathrm{q}_t^{e} + \left[\frac{(1-q)(1+l)(b+g)}{(s+h+l)(b+g)+jf} \right] \left\{ e_t^{m} - \frac{e_t^{z}}{a} - e_t^{d} + \frac{b e_t^{w}}{(b+g)} - \frac{e_t^{m}}{(1+l)} \right\}. \qquad (21)$$

An interesting feature of this solution is that both money supply and money demand shocks influence the real exchange rate in the sticky-price solution, whilst in the flexible-price solution they do not. Furthermore, in the flexible-price solution monetary shocks had an identical impact on both the price level and the nominal exchange, but in the sluggish-price-adjustment solution for the nominal exchange rate:

$$\mathrm{s}_t = \mathrm{s}_t^e + \left[\frac{(1-q)[(1-s-h)(b+g)-jf]}{(s+h+l)(b+g)+jf} \right] \left\{ e_t^m - \frac{e_t^z}{a} - e_t^d + \frac{be_t^w}{(b+g)} - \frac{e_t^{\mathrm{m}}}{(1+l)} \right\}.$$

The famous Dornbusch (1976) "overshooting effect" in response to money supply shocks (e_t^m) can be generated for $(1-s-h)(b+g)-jf>0$. Note that this order condition also implies an undershooting effect in response to money demand shocks (e_t^{m}), aggregate demand shocks (e_t^d), labour supply shocks (ε_t^{ω}), and productivity shocks (e_t^z).

Using (21) and the IS equation (1) to solve for the demand-determined level of output under sluggish price adjustment results in:

$$\mathrm{y}_t = \mathrm{y}_t^e + \left[\frac{(1-q)(1+l)[(s+h)(b+g)+jf]}{(s+h+l)(b+g)+jf} \right] \left\{ e_t^m - \frac{e_t^z}{a} - e_t^d + \frac{be_t^w}{(b+g)} - \frac{e_t^{\mathrm{m}}}{(1+l)} \right\}, \quad (22)$$

whilst using (20) and the labour demand equation (8) to solve for the demand-determined relative employment level under sluggish price adjustment yields:

$$\mathrm{l}_t = \mathrm{l}_t^e + \left[\frac{(1-q)(1+l)bj}{(s+h+l)(b+g)+jf} \right] \left\{ e_t^m - \frac{e_t^z}{a} - e_t^d + \frac{be_t^w}{(b+g)} - \frac{e_t^{\mathrm{m}}}{(1+l)} \right\}. \quad (23)$$

Both the output ratio and the employment ratio are now functions of all five shocks, and not only of technology or labour supply shocks. Home relative to foreign output and employment only gradually rises in response to technology and labour supply shocks under the short-run sticky-price solution. Furthermore, relative money supply and aggregate demand shocks boost home relative to foreign output and employment in the "short-run" under partial price adjustment, whilst relative money demand shocks depress the output and employment ratios temporarily.

Finally, using (18) and (19) to solve for the demand-determined level of nominal interest rate differentials results in:

$$\mathrm{i}_t = \mathrm{i}_t^e - \left[\frac{(1-q)[(1-s-h)(b+g)-jf]}{(s+h+l)(b+g)+jf} \right] \left\{ e_t^m - \frac{e_t^z}{a} - e_t^d + \frac{be_t^w}{(b+g)} - \frac{e_t^{\mathrm{m}}}{(1+l)} \right\},$$

which inserted in (11) jointly with (22) yields the demand-determined level of real balances:

$$\mathrm{m}_t - \mathrm{p}_t = \mathrm{m}_t^e - \mathrm{p}_t^e + (1-q)\left\{e_t^m - \frac{e_t^z}{a} - e_t^d + \frac{be_t^w}{(b+g)} - \frac{e_t^{\mathrm{m}}}{(1+l)}\right\}, \tag{24}$$

which again is a function of all five shocks.

The dynamic response of our five key variables to the various shocks in the "short-run" sluggish-price-adjustment solution can be summarized as:

$$\begin{bmatrix} \mathrm{l}_t \\ \mathrm{y}_t \\ \mathrm{s}_t - \mathrm{p}_t \\ \mathrm{m}_t - \mathrm{p}_t \\ \mathrm{p}_t \end{bmatrix} = \begin{bmatrix} f_{11} & f_{12} & f_{13} & f_{14} & f_{15} \\ f_{21} & f_{22} & f_{23} & f_{24} & f_{25} \\ f_{31} & f_{32} & f_{33} & f_{34} & f_{35} \\ f_{41} & f_{42} & f_{43} & f_{44} & f_{45} \\ f_{51} & f_{52} & f_{53} & f_{54} & f_{55} \end{bmatrix} \begin{bmatrix} e_t^w \\ e_t^z \\ e_t^d \\ e_t^{\mathrm{m}} \\ e_t^m \end{bmatrix}. \tag{25}$$

This matrix of "short-run" multipliers displays no neutrality characteristics, and all five variables are jointly driven by linear combinations of all five basic structural shocks. To achieve identification, we will focus on the "long-run" characteristics of the model.

2.2 Identification of the structural shocks

In order to identify our five structural shocks we employ the structural VAR technology, which is outlined in detail in Appendix A. The basic idea of this approach may best be illustrated by re-writing the flexible-price solution (20) as:

$$\begin{bmatrix} \mathrm{l}_t \\ \mathrm{y}_t \\ \mathrm{s}_t - \mathrm{p}_t \\ \mathrm{m}_t - \mathrm{p}_t \\ \mathrm{p}_t \end{bmatrix} = \mathrm{C}(\mathrm{L}) \begin{bmatrix} e_t^w \\ e_t^z \\ e_t^d \\ e_t^{\mathrm{m}} \\ e_t^m \end{bmatrix}, \tag{26}$$

where in order to allow for some short-term dynamics we have replaced the "long-run" multiplier matrix by a matrix polynomial C(L), which is a function of the lag polynomials in the various structural shocks. The long-run identifying restrictions adopted in this paper can then be written in terms of the long-run multipliers, that is, the elements of C(1). Setting the lag operator L equal to one results in the following specification of C(1):

$$C(1) = \begin{bmatrix} l_{11} & 0 & 0 & 0 & 0 \\ l_{21} & l_{22} & 0 & 0 & 0 \\ l_{31} & l_{32} & l_{33} & 0 & 0 \\ l_{41} & l_{42} & l_{43} & l_{44} & 0 \\ l_{51} & l_{52} & l_{53} & l_{54} & l_{55} \end{bmatrix}. \qquad (27)$$

In the empirical analysis below we rely exclusively on such long-run identifying restrictions, and we restrict C(1) to be lower block triangular. The structural VAR approach now is to estimate a reduced form VAR system in our five variables and to derive the structural shocks from the estimates of the reduced form shocks by imposing the above long-run impulse response matrix onto the estimates. Such long-run identifying restrictions were first proposed by Blanchard and Quah (1989), and other open economy applications include Ahmed, Ickes, Wang and Yoo (1993), Clarida and Galí (1995), Rogers (1995) and Canzoneri, Vallés and Vinals (1996). For a critical discussion of long-term restrictions see Faust and Leeper (1993) and Lippi and Reichlin (1993).

Before presenting any estimation results it is worth pointing out that none of the above identifying restrictions is particularly controversial. Like Shapiro and Watson (1988) and Blanchard and Quah (1989), we constrain aggregate demand shocks, money supply shocks and money demand shocks to have no permanent effect on the level of employment or output. In a similar fashion we follow Shapiro and Watson (1988) in constraining aggregate supply shocks to have no permanent effect on the level of employment. Furthermore, we follow Clarida and Galí (1995) in assuming that both monetary shocks have no long-run real exchange rate effects. Finally, we impose the standard neoclassical restriction that money supply shocks have a proportional long-run effect on money and prices and hence will not have any long-run effects on real money balances. We view these restrictions as being compatible with a wide range of open economy macro models, and the specification of our structural VAR has the advantage of yielding results which should be closely compatible with those obtained by Clarida and Galí (1995) in a smaller model.

A second aspect worth mentioning is that we view our combination of real and monetary variables as particularly relevant for simultaneously explaining both short-term exchange rate fluctuations and long-term real exchange rate movements. Our model explicitly combines long-run neoclassical aspects with short-term sluggish price adjustment. We believe that the empirical results derived from this model can easily be evaluated against a rich set of models of real exchange rate determination. Having labour and output in the model allows us to link our results to the Balassa-Samuelson hypothesis according to which differential movements in labour productivity (or more generally in production technology) are a key determinant of real exchange rate movements. Furthermore, having real money demand and money supply equations in a model with sluggish price adjustments enables us to judge the relevance of the "exchange rate overshooting" phenomenon popularized by Dornbusch (1976) in the monetary approach to the exchange rate.

3. Empirical results for the G3-economies

3.1 The data

In the econometric work we limit ourselves to seasonally-adjusted monthly data beginning in 1971.VIII and ending in 1994.XII. Our starting date stems from the start of the more freely floating exchange rate period, which can be dated back to the closing of the gold window by the U.S. Federal Reserve in August 1971.

Because of the use of six-month lags in estimating the VARs, our estimates cover only the years 1972 through 1994, or 276 observations.

Figures 1 and 2 present for all three bilateral combinations of the G3-economies the time-paths of the key macroeconomic variables under study. Note that these raw data point out two major breaks in the time-series: German real broad money balances exhibit a level jump after unification in 1991.I, and there is a major outlier in German industrial production during the strikes in June 1984. Adjustments were made for these breaks before estimating the VAR.[3]

The data in Figures 1 and 2 are organized in a way that is most relevant for the issues under study in the present paper. Figures 1a to 1c display the nominal exchange rates against the ratio of consumer prices in each country. For each bilateral combination of countries the consumer price ratios have moved substantially less than the corresponding exchange rates, hence there are substantial real exchange rate movements. PPP therefore does not seem to hold very well. In Figures 1d to 1f we follow the monetary approach to exchange rate determination and replace the price indices by the ratio of two money demand functions, which for simplicity feature a unit income elasticity and zero interest elasticity. For both yen exchange rates this tracks nominal exchange rate movements much better than the above price ratios prior to the year 1982. Interestingly, monetary factors again work quite well after 1986 for the yen exchange rates, but they do not mirror exchange rate movements during the U.S. dollar hike of 1982-1985. However Figures 1d to 1f suggest that monetary factors may be important for understanding the early and late episodes of nominal yen exchange rate movements.

Figure 2 analyses the real exchange rate impact of the real variables included in our model. Figures 2a to 2c look at bilateral real exchange rate movements and

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[3] Since real money turned out to be I(1) in our stationarity tests, we replaced the jumps in the monthly growth rates at those points in time by the average growth rate in the six months before the break but after unification.

output ratios. We find persistent deviations, but the long-run trends of both variables roughly coincide. Figures 2d to 2f look at the relationship between real exchange rates and productivity ratios. Here we find by far the strongest link between our fundamental variables and exchange rates. As before, the hike of the dollar is not reflected by these fundamentals, but prior to 1982 there is a close comovement. This suggests that in addition to monetary factors some real factors, such as productivity differentials, also seem to play an important role in accounting for real exchange rate movements. Since we include money, prices, output and employment in our real exchange rate model we should be able to judge the relevance of this conjecture empirically.

An important stilized fact from Figures 1 and 2 is that PPP deviations are quite persistent and long-lived for the G3 economies, with typical estimates suggesting that PPP deviations tend to vanish with a half-life of around 3-5 years. The smooth relative price level movements furthermore imply that in the short-run real and nominal exchange rate movements tend to be highly correlated. To explain these persistent real exchange rate movements we will now turn to our structural VAR estimation results. We will analyse the components of real exchange rate movements due to each type of shock. We will also report impulse response functions and variance decompositions for real exchange rates over various time horizons in order to determine whether the same factors, which drive the short-term volatility of real exchange rates, also determine their medium-term swings and long-run movements.

3.2 Time series properties of the data: unit roots and cointegration

This paper aims at estimating the system $x=[\Delta l_t,\Delta y_t,\Delta s_t-\Delta p_t,\Delta m_t-\Delta p_t,\Delta p_t]$, whereby the variables in x are defined as follows: Δl_t is the first difference in the logarithm of the employment ratio, Δy_t is the first difference in the logarithm of industrial production ratio, $\Delta s_t-\Delta p_t$ is the logarithm of the bilateral real exchange rate, with Δs_t as the change in the nominal bilateral exchange rate and Δp_t as consumer price inflation, and Δm_t-Δp_t corresponds to the change in real money balances, where Δm_t is the change in the logarithm of the ratio of broad monetary aggregates (M2). By appropriate transformations these five variables also uniquely determine the ratio of money growth rates Δm_t, the nominal exchange rate Δs_t, and average labour productivity Δy_t-Δl_t. The above specification of the degree of time differencing and drift or trend adjustment of the variables in x is outlined in detail in Table 1a to 1c, which report the results of prior unit-root tests. Amongst the G3-countries all bilateral output and employment ratios were found to be integrated of order one, I(1). The ratios of price levels are also integrated of order one, I(1). The only exception here is the case of the United States relative to Japan, where there is some (weak) indication of a trendstationary process. We decided nevertheless to treat all three G3-combinations symmetrically, but the above test indicates that some care should be exercised when interpreting the results. Real exchange rates in all three G3 combinations were found to be I(1). Finally, productivity and velocity were both found to be I(1), which again implies that real money ratios and output ratios as well as output ratios and employment ratios cannot be cointegrated, since the linear combinations of these variables do not result in stationary stochastic processes. To summarize, we found that, with the exception of the consumer price ratio between the United States and Japan, all ratios of the relevant variables under study were integrated of order one. In order to estimate the SVAR we used first differences and adjusted the growth rates for deterministic drifts and trends according to the decisions indicated in Tables 1a to 1c.

Estimating the SVAR model in first differences may result in a loss of information if there exists a long-run cointegrating relationship between the nonstationary variables. To check this we performed a multivariate cointegration analysis as a second set of pre-tests. As is reported in Table 1d, no cointegration was found for both combinations relative to Japan, whilst one cointegrating vector may be present for the case of Germany relative to the United States. Since cointegration does not seem to be a major problem we decided to estimate the same specification for all bilateral combinations of G3-countries, but Table 1d indicates that some caution should be exercised when interpreting these results.

3.3 Estimation Results

In this section we represent our empirical results, with which we seek to answer a number of questions: first, what are the sources of real exchange rate movements since the collapse of the Bretton Woods system, and, in particular, do nominal shocks play a major role? We also want to challenge the results derived by Clarida and Galí (1995), who find that demand shocks explain the majority of real exchange rate movements, whilst supply shocks explain very little. Is this result robust with respect to our extension of their model? To answer these questions, we estimate an unrestricted VAR using a lag window of length four,[4] and then impose our long-run identification scheme onto the data. We look at three complementary ways of summarizing the results of the structural VAR: we first consider the impulse responses of employment, output, real exchange rates, real money balances and prices to the various shocks in order to determine whether or not the effects of shocks to labour supply, technology, aggregate demand, money demand or money supply identified under our approach appear as they should. We also compute the variance decomposition of the real exchange rate and "real time" historical decompositions of the real exchange rate to see whether or not our results make sense.

3.3.1. Impulse Responses

Figures 3 displays the impulse responses of the real exchange rate to the various one-standard deviation shocks. The standard error bands were obtained by

[4] Our results were not very sensitive with respect to the length of the lag window. Similar results were obtained by using alternative lag windows of length six or nine, but in these cases the impulse response functions indicated some degree of overparameterization of the VAR.

Monte Carlo simulation. Both in qualitative and quantitative terms, these results closely resemble those of Clarida and Galí (1992). Also note that our results are fairly consistent across countries and relatively robust, even if some individual impulse responses occasionally fail the 5 percent significance tests. The major impulse response of real exchange rates is found with respect to aggregate demand shocks. For all three exchange rates these shocks have a highly significant impact over all time horizons, and the correlation between these impulse responses is high and close to one. Money demand and money supply shocks by construction only have short-run real exchange rate effects, which tend to become insignificant over 2-months and 8-months horizons, respectively. Supply shocks also have only a very short-run impact on U.S. dollar real exchange rates, but produce quite persistent significant effects for the DM/YEN rate. Finally, labour market disturbances have a highly significant and persistent effect on the yen real exchange rates, but play no role for the DM/$ rate. This suggest that fundamental real factors matter more for the yen exchange rates than for the U.S. dollar exchange rates.

The above results are interesting, because they point towards an important asymmetry between the G3-economies. But do the results make sense? Figure 3 says that the real exchange rate appreciates with respect to relative demand shocks. Figures 4 to 5 furthermore show that, as in Clarida and Galí (1995), relative demand shocks increase the relative price level and raise relative output. So, does this relative demand shock pass the duck test?[5] In Clarida and Galí (1995) it does. But in the present paper there are some doubts. In the case of Germany versus Japan the relative demand shocks raises employment and lower the demand for real money balances (Figures 6 to 7), as is predicted by theory, but for the two relationships relative to the United States the results are less clear-cut. What is even more disturbing is the fact that the output (or employment) impact of the demand shocks

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[5] See Clarida and Galí (1995): "If it walks like a duck and quacks like a duck, it must be .... "

is insignificant in all three cases over all time horizons. This fact is not visible from the results reported by Clarida and Galí (1995), since they only report the mean output responses, but not the significance bounds. Thus, whilst the estimates of the impulse responses largely support our interpretation of the structural shocks, there is some doubt with respect to the labelling of the aggregate demand shock. To obtain additional information on this key aspect of the paper, we now turn to the analysis of the variance decompositions.

3.3.2. Variance Decompositions

Table 2 reports the variance decomposition for output, the real exchange rate and prices. Labour supply and technology shocks dominate the conditional variance of output over all time horizons except for the United States relative to Japan, where money demand disturbances contribute a lot to short-term output variability. The conditional volatility of relative prices between the U.S. and Germany is largely due to relative money supply shocks, but for Japan relative to the other two countries labour supply, aggregate demand and money demand shocks matter almost equally as much over the long horizon. Finally, most of the short-term conditional variance in the level of real exchange rates can be attributed to demand shocks (60-85 percent) and a much smaller proportion to monetary shocks (10-20%), whilst supply shocks play virtually no role. Long-term real exchange rate variability relative to Japan, however, has a substantial labour market component. This again suggests that the variability of the yen exchange rates is more due to fundamentals than that of the U.S. dollar exchange rates.

3.3.3. Historical decompositions in shock components

Figure 8 displays the components of real exchange rates due to the various shocks, together with the correlation coefficients between these shocks and the stochastic trend deviation of the real exchange rate. The various panels of Figure 8 also report the conditional forecast error variance decomposition of real exchange rates due to the various shocks over short-term and long-term forecast horizons (vs denotes one month and vl denotes 36 month). The key finding here is that relative demand disturbances in the terminology of Clarida and Galí (1995) are highly correlated with real exchange rates and virtually map them one-for-one in the case of the DM/$ rate. For the yen real exchange rates the mapping is less perfect owing to the substantial labour market component of these real exchange rates. Nevertheless, the figures clearly reveal that the aggregate demand disturbance is a catch-all variable that reflects any component of real exchange rate movements which cannot be forecast from the other structural shocks in the model. Take the case of the smaller version of our SVAR analyzed by Clarida and Galí (1995): since monetary shocks have no long-run real exchange rate impact by construction, their measure of the relative demand shock basically equals that component of real exchange rate movements which is not correlated with relative output movements in the long-run. The less long-run correlation there is between output and real exchange rates, the higher is the so-called demand shock component of real exchange rates. In this interpretation the proposed measure of relative demand shocks really equals a „measure-of-ignorance“ with respect to the sources of real exchange rate movements. It is obvious that this point applies more generally to all strictly triangular long-run structural VAR identification shemes: the shock in row k of the vector ε is the only shock which is allowed to influence the endogenous variable in row k of the vector x without being limited by the behaviour of other specific variables.

A second interesting finding of the present paper is that relative labour market disturbances appear to be important in capturing the long-run trend of the real yen exchange rates relative to the other G3-economies, both in terms of their time profile and their variance decomposition. This indicates that fundamentals matter for the yen.

4. Conclusions

Recent research into the sources of real exchange rate movements has produced some surprising new results. Clarida and Galí (1995) report that demand shocks, such as shocks to national savings or investment, explain most of the variance in real exchange rate fluctuations for the U.S. dollar exchange rates of the G3-economies, whilst supply shocks and monetary shocks do not appear to matter much, except perhaps over very short time horizons. The fact that real demand shocks rather than monetary shocks dominate short-term real exchange rate movements may explain why deviations from PPP die out at such a low rate. But it is surprising that aggregate demand shocks rather than supply or productivity shocks should play the key role for medium to long-term real exchange rate movements.

The present paper reconsiders this evidence in an extended version of the Clarida and Galí (1995) model by splitting supply shocks into labour supply and productivity shocks, and by viewing monetary shocks as being composed of money demand and money supply shocks. This does not overturn the results of Clarida and Galí (1995) for the U.S. dollar exchange rates. However, we find that relative demand disturbances in the terminology of Clarida and Galí (1995) are extremely highly correlated with real exchange rates and virtually map into them almost one-to-one. We also show that these "demand shocks" lack a significant output impact at all time horizons, casting serious doubt on the interpretation of these shocks as being "aggregate demand shocks". To use the terminology of Clarida and Galí (1995), the relative demand shocks fail the most simple "duck test". The aggregate demand disturbance is a catch-all-variable which reflects real exchange rate movements, which cannot be forecasted from the other structural shocks in the model. This bias of the Clarida and Galí (1995) identification scheme towards over-emphasizing the importance of demand shocks is also obvious from the results of Canzoneri, Vallés and Vinals (1996). Given the well-known problems in linking real or nominal exchange rate movements to economic fundamentals, the emphasis of Clarida and Galí (1995) on demand shocks as the key component of this residual is highly questionable and potentially misleading.

A second interesting result of the present paper is that with respect to the real exchange rates of the Japanese yen real economic fundamentals appear to matter to some extent. In particular, relative labour supply shocks explain roughly a third of the real exchange rate variability of the yen over the long-run horizon. Labour market disturbances also have a significant short-run and long-run real exchange rate impact on the yen. Thus, the evidence for Japan is more in line with the Balassa-Samuelson view that differential labour and product market developments may have important consequences for real exchange rates and international competitiveness.

Appendix A: Structural VARs and Identification

This exposition of the structural VAR technology closely follows Galí's (1992) paper and largely adopts his notation. Assume that $x=[x_1,x_2,x_3,...,x_k]$ is a covariance stationary vector process. Each element in x has zero mean, or rather, has been demeaned or detrended. Assume also that each element in x can be expressed as a linear combination of current and past structural shocks $\varepsilon=[\varepsilon_1,\varepsilon_2,\varepsilon_3,...,\varepsilon_k]$. Formally, x has a moving average representation, as described in equation (26) in the main text, and is given by:

$$x=C(L)\varepsilon. \quad \text{(A1)}$$

The reduced form Wold moving average representation is given by:

$$x=E(L)\eta, \quad \text{(A2)}$$

where $E(L)=[E_{ij}(L)]$, $E(0)=I$, and $E(L)$ is required to be invertible. The vector of reduced form shocks $\eta=[\eta_1,\eta_2,\eta_3,...,\eta_k]$ is assumed to have a zero mean vector and a variance covariance martrix Ω. The reduced form autoregressive representation in terms of the shocks η is given by:

$$B(L)x=\eta, \quad \text{(A3)}$$

with $B(L)=[B_{ij}(L)]$, $B(L)=E(L)^{-1}$, and $B(0)=I$, whilst the autoregressive representation in terms of the structural shocks ε follows as:

$$A(L)x=\varepsilon, \quad \text{(A4)}$$

with $A(L)=[A_{ij}(L)]$, $A(L)=C(L)^{-1}$ and $A(0)=S^{-1}$. The reduced form innovations η are assumed to be a linear combination of the structural disturbances ε:

$$\eta=S\varepsilon. \quad \text{(A5)}$$

Given equations (A1) and (A2) this implies

$$C(L)=E(L)S. \quad \text{(A6)}$$

Since OLS estimation of equation (A3) yields estimates of B(L) and hence estimates of its inverse, $E(L)=B(L)^{-1}$, the matrix C(L) can be uniquely identified to the extent that we introduce enough restrictions to just-identify the matrix S.

How may such restrictions be derived? First, it is straightforward to assume that the structural shocks ε are mutually orthogonal, which together with a convenient normalization condition[6] implies that $E(\varepsilon\varepsilon')=I$. Using this normalizing condition together with equation (A5) implies:

$$SS'=\Omega, \qquad (A7)$$

and this factorisation provides k(k+1)/2 non-linear restrictions on the elements in S, given the OLS estimate of the variance-covariance matrix Ω of the reduced form errors η. This leaves us with the problem of determining the remaining k(k-1)/2 restrictions on the elements of S.

To achieve just-identification in our SVAR with k=5 disturbances requires k^2 restrictions. As discussed above, the orthogonality condition $SS'=\Omega$ implies a set of k(k+1)/2=15 restrictions for the matrix S, which leaves us with k(k-1)/2=10 restrictions for S to be derived from economic theory in order to identify the vector of structural shocks $\varepsilon=[\varepsilon_t^{\omega},\varepsilon_t^{z},\varepsilon_t^{\delta},\varepsilon_t^{m},\varepsilon_t^{\mu}]$. Here we employ the results from our theoretical model, as outlined in equation (26) in the main text.

6 This normalization ensures that the vector of shocks is measured in terms of one standard deviation of the corresponding variable in the vector x

Appendix B: Time series and data sources

All data are monthly, seasonally adjusted data. In case the original data were not seasonally adjusted, seasonal adjustment was carried out using the GAUSSX procedure SAMA. The time series and data sources used were:

Output (industrial production, index): IMF, International Financial Statistics, various issues, Employment: IMF, International Financial Statistics, various issues. Consumer price indices: IMF, International Financial Statistics, various issues, line 64. Monetary aggregate M2, national definition: IMF, International Financial Statistics, various issues. Nominal exchange rates :IMF, International Financial Statistics, various issues. Real exchange rates, real money balances: own calculations using nominal exchange rates, consumer price ratios and nominal money stocks.

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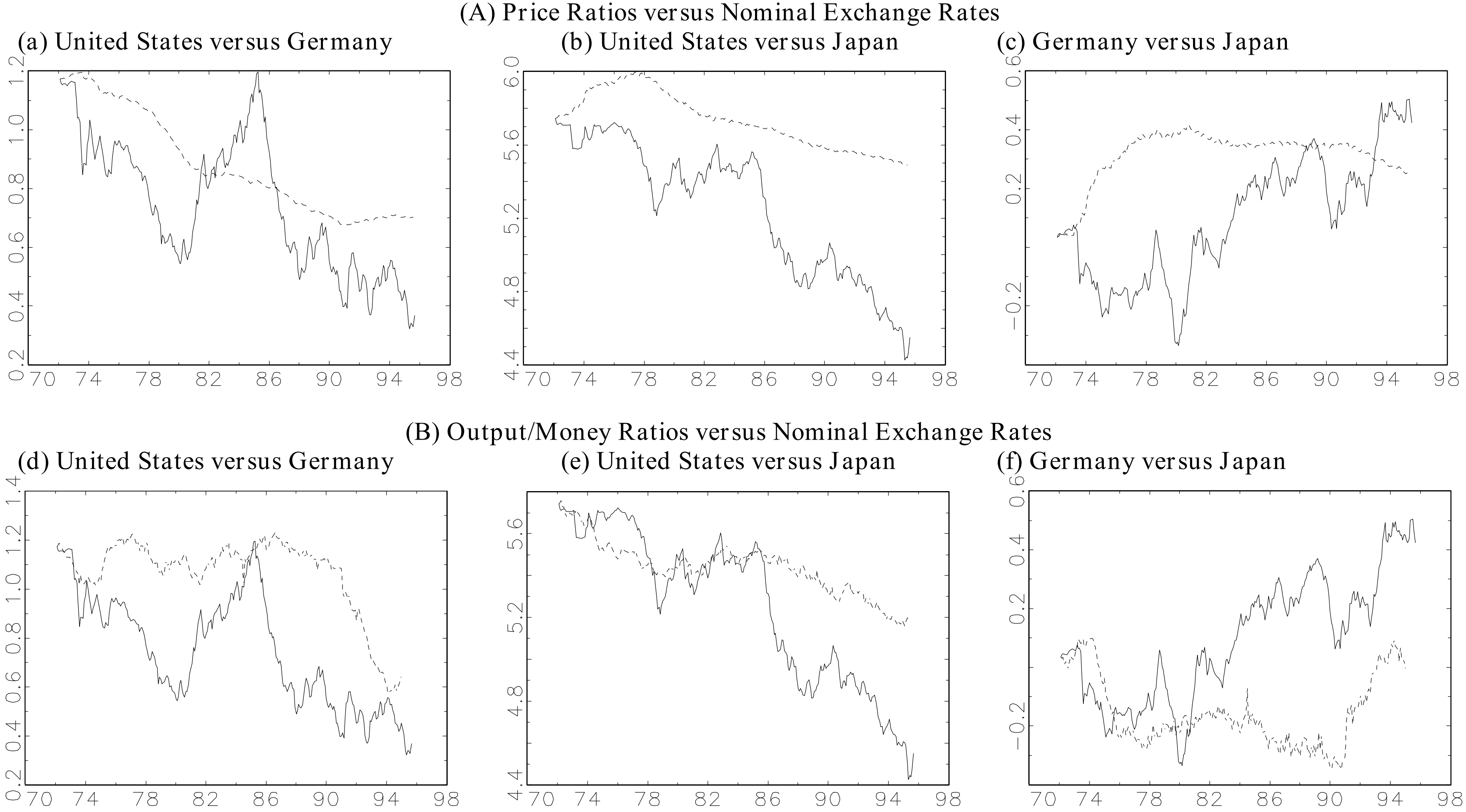
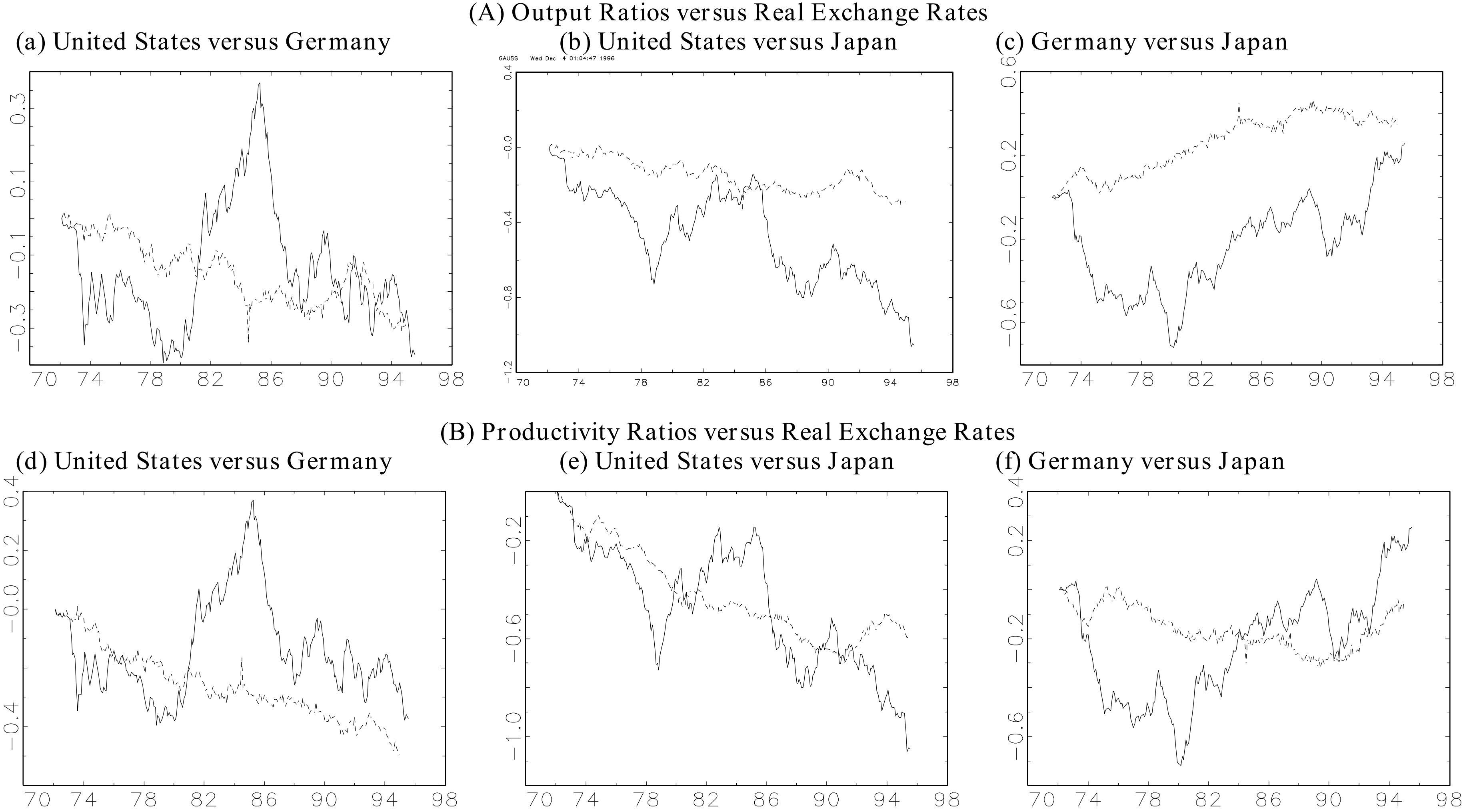
Figure 1: Nominal Exchange Rates, Price Ratios, and Money-Output Ratios, Logarithms, 1972-1996



Key to Figure: ________ Log of Nominal Exchange Rate - - - - - - Log of Price Ratio (a-c), Money/Output Ratio (d-f)

Figure 2: Real Exchange Rates, Output Ratios, and Productivity Ratios, Logarithms, 1972-1996



Key to Figure: ________ Log of Real Exchange Rate - - - - - - Log of Output Ratio (a-c), Productivity Ratio (d-f)

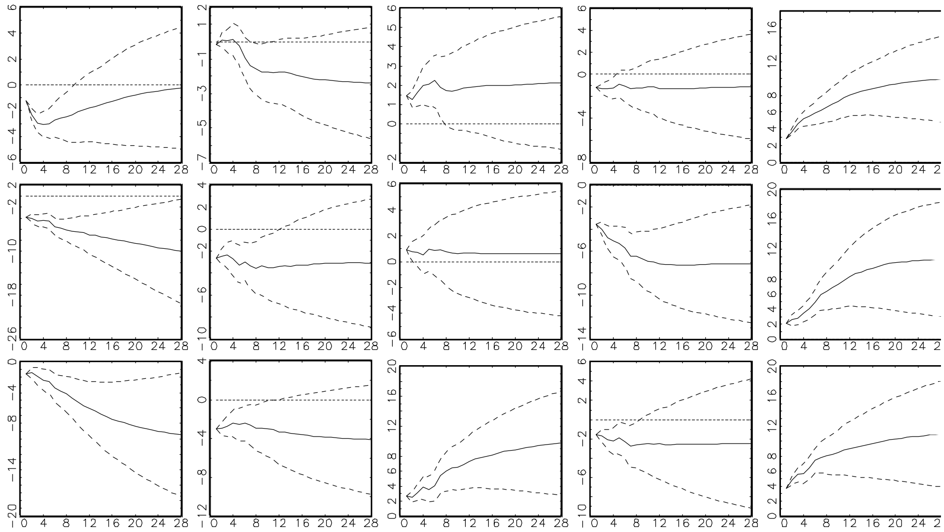
Figure 3: Impulse Response of the Relative Price Ratios of the G3-Countries to Various Shocks, Monthly Data, 1972.I-1994.XII

Labour Market Shock | Aggregate Supply Shock | Aggregate Demand Shock | Money Demand Shock | Money Supply Shock

U.S. relative to Germany

U.S. relative to Japan

Germany relative to Japan



Key: The solid lines are the mean response of the ratio of log levels of consumer prices to a one standard deviation shock. The dashed lines are the 2 standard error bands obtained by Monte Carlo simulation.

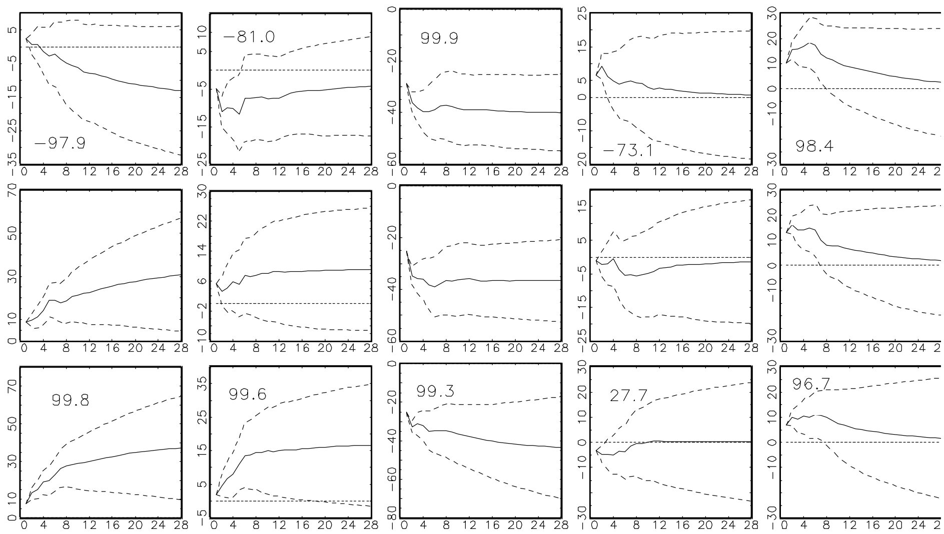
Figure 4: Impulse Response of the Real Exchange Rates of the G3-Countries to Various Shocks, Monthly Data, 1972.I-1994.XII

Labour Market Shock | Aggregate Supply Shock | Aggregate Demand Shock | Money Demand Shock | Money Supply Shock

U.S. relative to Germany

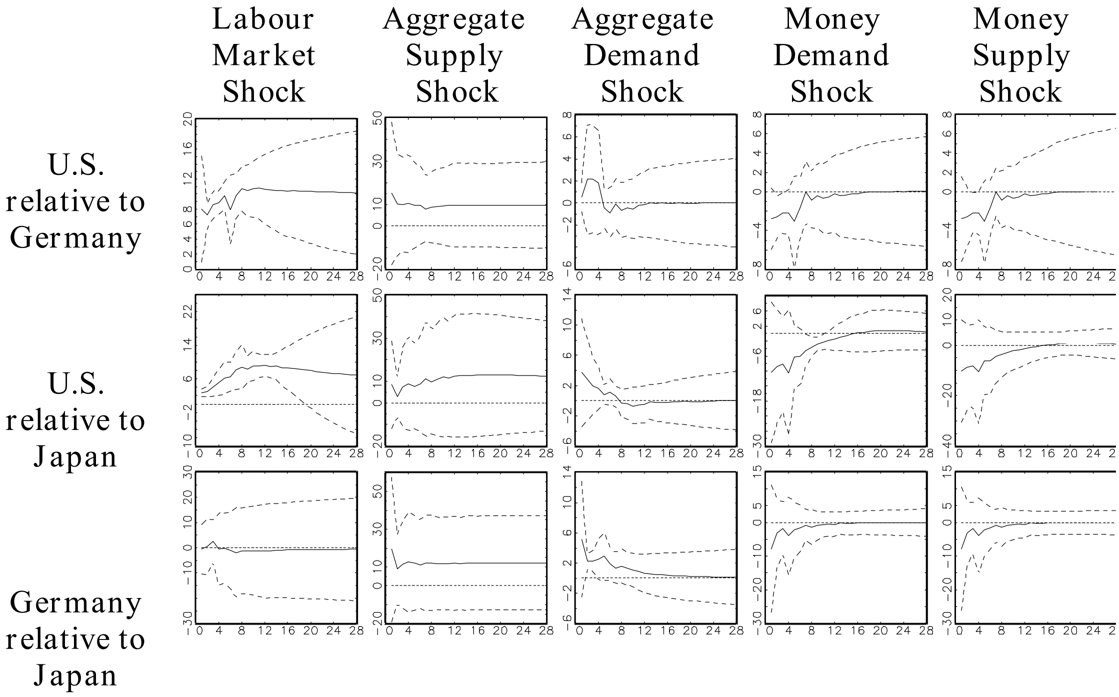
U.S. relative to Japan

Germany relative to Japan



Key: The solid lines are the mean response of the log levels of the real exchange rate (log level of the nominal exchange rate minus the ratio of the log levels of consumer prices) to a one standard deviation shock. The dashed lines are the 2 standard error bands obtained by Monte Carlo simulation. The numbers indicate the correlations with the corresponding impulse response funtions for the United States relative to Japan.

Figure 5: Impulse Response of the Output Ratios of G3-Countries to Various Shocks, Monthly Data, 1972.I-1994.XII



Key: The solid lines are the mean response of the ratio of log levels of industrial production to a one standard deviation shock. The dashed lines are the 2 standard error bands obtained by Monte Carlo simulation.

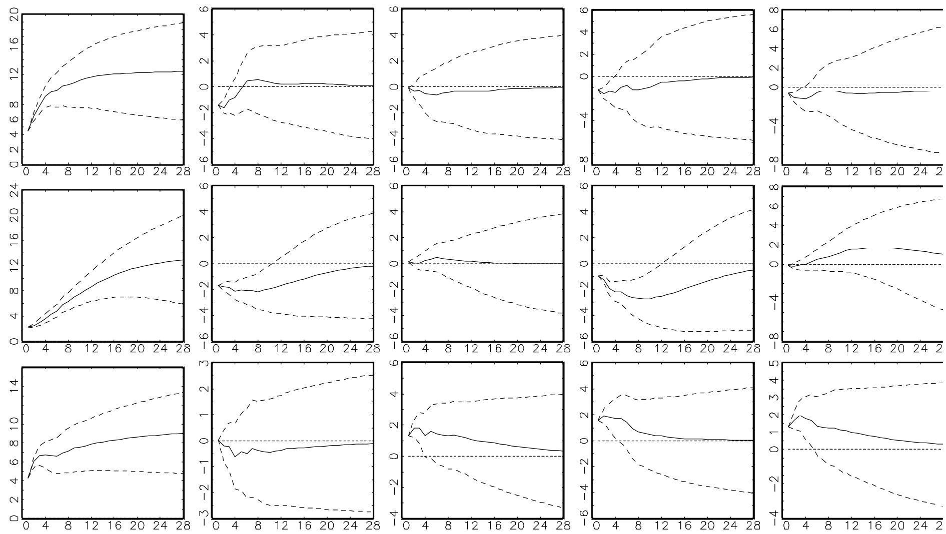
Figure 6: Impulse Response of the Employment Ratios of G3-Countries to Various Shocks, Monthly Data, 1972.I-1994.XII

Labour Market Shock	Aggregate Supply Shock	Aggregate Demand Shock	Money Demand Shock	Money Supply Shock

U.S. relative to Germany

U.S. relative to Japan

Germany relative to Japan



Key: The solid lines are the mean response of the ratio of log levels of employment to a one standard deviation shock. The dashed lines are the 2 standard error bands obtained by Monte Carlo simulation.

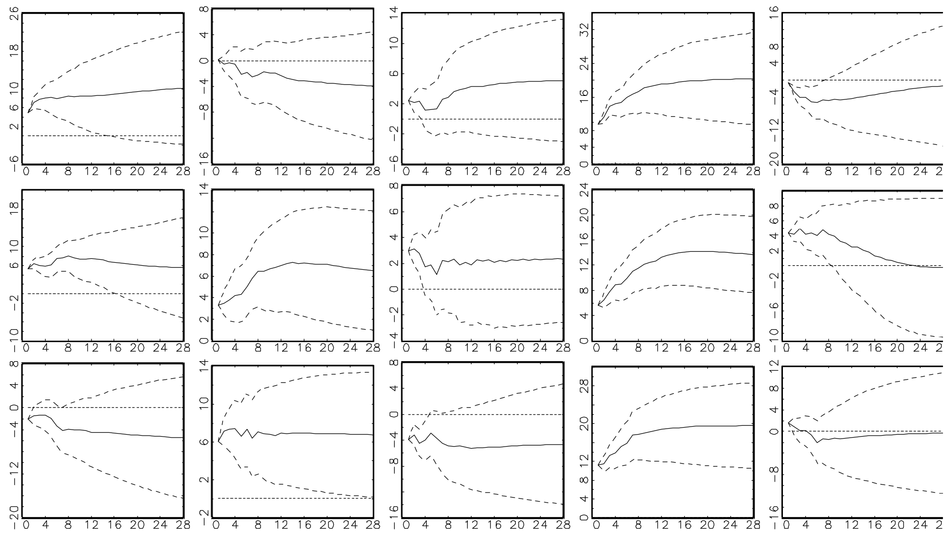
Figure 7: Impulse Response of the Real Money Balances of G3-Countries to Various Shocks, Monthly Data, 1972.I-1994.XII

	Labour Market Shock	Aggregate Supply Shock	Aggregate Demand Shock	Money Demand Shock	Money Supply Shock

U.S. relative to Germany

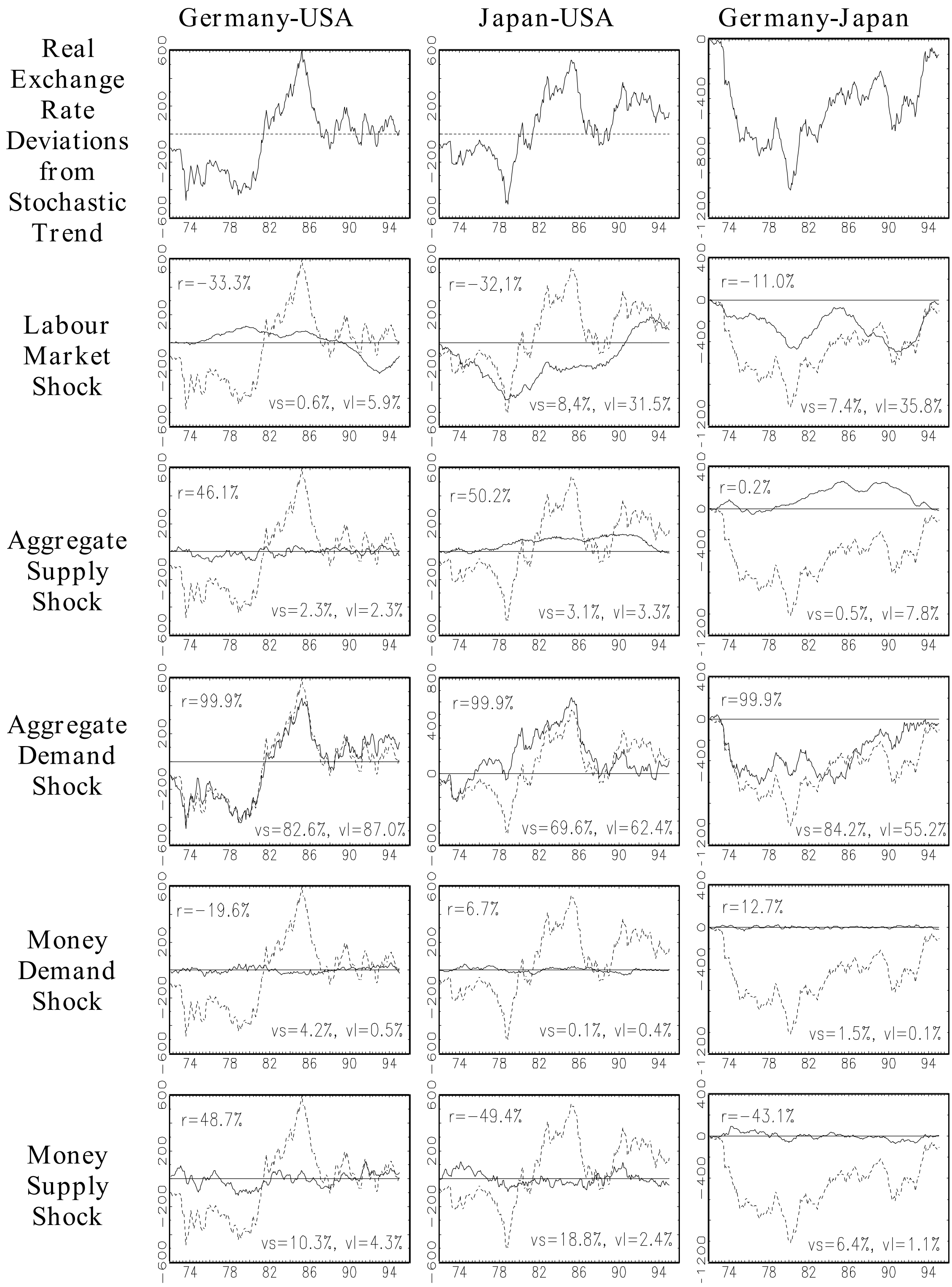
U.S. relative to Japan

Germany relative to Japan



Key: The solid lines are the mean response of the ratio of log levels of real money balances (M2/P) to a one standard deviation shock. The dashed lines are the 2 standard error bands obtained by Monte Carlo simulation.

Figure 8: Components of Stochastic Trend Deviations of the Real Exchange Rate for the G3-Countries, Monthly Data, 1972.I-1994.XII



Key: The dashed line is the stochastic trend deviation of the real exchange rate and the solid line indicates its shock components. r denotes the correlation coefficient, vs and vl are the contribution of each shock to the exchange rate variance at short (zero month) and long (36 month) time horizons, respectively.