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Real and Nominal Exchange Rates in the Long Run

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Abstract

This paper decomposes longer-run movements in (major) dollar real exchange rates into components associated with changes in nominal exchange rates and price levels, and their comovements. Though the decompositions suggest some permanent movements, they imply that there are large transitory components in real exchange rates. These transitory components in real exchange rates are found to be closely associated with those in nominal exchange rates. A stochastic version of Dornbusch's overshooting model--configured with representative parameter values for the United States and subjected to permanent nominal shocks--can rationalize these transitory comovements of nominal and real exchange rates as well as several other features of the decompositions.

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F31, C50

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Contents

Summary

Asset-market models of exchange rate determination are distinguished by their stress on stock equilibrium effects. Monetary models can be distinguished from more general portfolio-balance models by the assumed degree of substitutability between domestic and foreign assets. Early monetary models assumed flexible prices and continuous purchasing power parity (PPP), although this was remedied in the second generation, "overshooting" monetary models.

The broad conclusion which emerges from the empirical evidence is that while the asset-approach models have performed reasonably well for some periods, such as the interwar period and the first few years of the recent float (1973-78), they have largely failed to explain the behavior of the major exchange rates since 1978.

A number of hypotheses have been put forward to explain this phenomenon, including views concerning the effect of "non-fundamentals," such as chart analysis and political factors, on exchange rate behavior. Other researchers have argued that standard exchange rate equations may be misspecified in one or more ways and have suggested, for example, the use of structural, rather than reduced form, models.

Under the efficient-markets hypothesis (EMH), it should be impossible for a trader to earn excess returns to speculation. The EMH is, in fact, a joint hypothesis consisting of rational expectations and an assumption concerning the attitude of agents toward risk. Methods of testing the EMH include testing the profitability of simple trading rules ("filter rules"), testing the implication of the EMH that (under risk neutrality) the forward rate should be an optimal predictor of the future spot rate, and testing for the statistical independence of exchange rate forecast errors with respect to past information. There is now overwhelming evidence to suggest that the forward foreign exchange rate is a biased and inefficient predictor of the future spot rate. The simple EMH (i.e., one assuming risk neutrality) thus appears to have been decisively rejected. Evidence for the existence of a time-varying risk premium is, at best, mixed, while tests using data on surveys of expectations in the foreign exchange market tend to reject the rational-expectations hypothesis.

The empirical evidence on the various international parity conditions suggests the following. First, the covered-interest-parity condition (that the nominal-interest-rate differential is just equal to the forward exchange rate premium) receives fairly strong support, especially for Eurodeposit interest rates. The uncovered-interest-parity condition (that the expected rate of exchange rate depreciation is just equal to the nominal interest rate differential) is resoundingly rejected. Similarly, real interest rate parity is often easily rejected. The empirical literature on PPP rejects the hypothesis of continuous PPP, while the hypothesis of long-run PPP receives mixed support.

I. Introduction

Much attention has been paid to whether real exchange rates among major currencies show a tendency to revert over time to a fixed mean as suggested by the hypotheses of relative and absolute purchasing power parity. (See Isard (1988), Levich (1985), and Campbell and Clarida (1987), and the references cited therein, for a discussion of the recent evidence on purchasing power parity.) Using spectral procedures, a number of studies has found evidence of a preponderance of negative autocorrelations in real exchange rate changes at long lags, implying temporary components in real exchange rate changes that are reversed over time and the possibility of long-run mean reversion. The statistical significance of this evidence, however, has been difficult to establish 1/ (given the limited degrees of freedom at long lags), leaving the relative importance of the permanent and transitory components of real exchange rate changes unclear. (See Adams and Chadha (1990), Huizinga (1987) and Kaminsky (1987) and Campbell and Clarida (1987).)

This paper sheds light on how any tendency toward mean reversion in real exchange rates is brought about by decomposing estimates of the spectral density for real exchange rate changes at frequency zero into components associated with changes in nominal exchange rates and price levels (and their covariances). The decompositions show whether changes in nominal exchange rates or changes in price levels are primarily responsible for any apparent mean reversion in real exchange rates. In addition, by providing information on the covariances between changes in nominal exchange rates and price levels at various lags, the decompositions provide additional evidence against which hypotheses about exchange rate behavior should be considered.

The paper's main finding is that much of the long-run negative autocorrelation in real exchange rate changes is associated with negative autocorrelation in nominal exchange rate changes. This finding, which implies that the transitory movements in real exchange rates are closely associated with those in nominal exchange rates, is interpreted as suggestive of a role for overshooting and the kinds of intrinsic dynamics associated with sticky-price monetary models. Using representative parameter values for the U.S. economy, the paper shows that a version of Dornbusch's sticky-price monetary model subjected to permanent nominal shocks is able to rationalize the negative autocorrelation in nominal and real exchange rate changes. In addition--in response to permanent nominal shocks--simulations of the model produce values for the components of the spectral density for real exchange rate changes at long lags that in a number of other respects are very similar to those found in the data. Even though the simulations are suggestive of a role for nominal shocks and

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1/ The null hypothesis tested is that the real exchange rate follows a random walk, implying that all changes are permanent and purchasing power parity does not hold.

intrinsic dynamics in understanding exchange rate movements we stop short of claiming that we know what these shocks are given the failure of empirical exchange rate models. Instead, we interpret these results as pointing to a role for some kind of broadly defined nominal shocks, which could take the form either of unobservable shifts in money supplies or money demands. (See Meese and Rogoff (1983a,b), Adams and Boyer (1987), and Adams and Chadha (1990) for a discussion of the performance of these models.)

The remainder of the paper is organized as follows. Section 2 describes the spectral procedure used to decompose longer-run changes in real exchange rates into components associated with changes in nominal exchange rates and price levels. Section 3 presents estimates of the spectral densities and their decompositions for changes in several bilateral dollar real exchange rates over the recent floating rate period. This is followed in Section 4 by the calculation of the spectral densities obtained when the Dornbusch overshooting model is simulated in response to a variety of nominal and real shocks. Comparisons between these simulated spectral densities for real exchange rate changes and the ones estimated from the actual data provide evidence about the kinds of shocks which might lie behind exchange rate movements. Finally, Section 5 summarizes the results and discusses their implications for the interpretation of the negative autocorrelation in real and nominal exchange rate changes. The paper is followed by a short appendix describing the version of the Dornbusch model used in the simulations.

II. Spectral Procedure and Decompositions

The spectral procedure used in this paper was first applied to real exchange rates by Huizinga (1987), Kaminsky (1987), and Adams and Chadha (1990). (For other applications, see Cochrane (1986) and Fama and French (1986).) By examining the longer-run autocorrelations of real exchange rate changes, the procedure seeks to determine whether there is any tendency for real exchange rates to revert to a fixed mean in the long run as implied by the hypothesis of purchasing power parity. In addition, the procedure provides estimates of the relative significance of the transitory and permanent components of real exchange rate changes, with the limiting case of mean reversion indicating the absence of permanent components. The procedure involves estimating the ratio of 2π times the spectral density of the (logarithmic) first difference of the real exchange rate at frequency zero to the variance of its (logarithmic) first difference. This ratio or 'normalized' spectral density, g(0), can be written in terms of the autocorrelations of real exchange rate changes as follows where, for convenience, we work with a simple transformation of the normalized density, denoted f(0), which is defined as g(0) minus one 1/

1/ This transformation makes the interpretation of the statistic for the presence of negative or positive autocorrelations more transparent.

$$f(0) = g(0) - 1 = 2 \sum_{i=1}^{\infty} \rho_i . \qquad (1)$$

Here ρ_i is the autocorrelation at lag i of the (logarithmic) first difference of the real exchange rate. The 'spectral density', f(0), as defined in equation (1), cannot fall below minus one but can assume any other value. When the spectral density is positive there is a preponderance of positive correlations and when it is negative, negative correlations dominate.

Alternatively, following Beveridge and Nelson (1981) and Huizinga (1987), the spectral density at frequency zero can be written in terms of the ratio of the variance of the change in the permanent component of the real exchange rate to the variance of its total change as given by equation (2). 1/

$$f(0) = Var[z_t - z_{t-1}]/ Var[q_t - q_{t-1}] - 1. \qquad (2)$$

Here $z_t - z_{t-1}$ denotes the permanent component of the (logarithmic) change in the real exchange rate and $q_t - q_{t-1}$ is the actual (logarithmic) change. Equations (1) and (2) represent alternative ways of presenting information about long-run changes in real exchange rates and measuring the importance of permanent changes. 2/

The spectral density (as given by either equation (1) or (2)) is important for the question of mean reversion in real exchange rates because it is equal to minus unity in the case of any stationary series. 3/ A value of the spectral density close to minus unity is indicative therefore of stationarity and the possible absence of permanent components in real exchange rates. Conversely, when the real exchange rate follows a random walk (in which all changes are permanent) the spectral density equals zero. Values of the spectral density between zero and minus unity, on the other hand, are indicative of the real exchange rate having both transitory and permanent components. A value of the spectral density above zero indicates positive autocorrelations in real exchange rate changes and a tendency for changes to be reinforced over time.

1/ As discussed by Huizinga (1987), this alternative representation of the spectral density applies to any decomposition of a unit root process into transitory and permanent components and not just the Beveridge-Nelson decomposition.

2/ Note that one minus the ratio of the variance of permanent changes to the variance of total changes cannot in general be interpreted as the share of temporary changes since the temporary and permanent components may be correlated.

3/ For further details see Huizinga (1987) and Adams and Chadha (1990). Note that in contrast to these authors, we have normalized the spectral density around zero rather than unity.

The (log of the) real exchange rate, q, is defined as the sum of (the log of the) nominal exchange rate, e, expressed as the number of units of domestic currency per unit of the foreign currency, and the (log of the) ratio of relative price levels, p ($P^* - P$), that is

$$q_t = e_t + p_t. \tag{3}$$

Substituting equation (3) into equation (1) yields

$$f(0) = 2 \sum_{j=1}^{\infty} \left[\frac{C(\tilde{e}_t, \tilde{e}_{t-j})}{\sigma_{\tilde{q}}^2} + \frac{C(\tilde{p}_t, \tilde{p}_{t-j})}{\sigma_{\tilde{q}}^2} + \frac{C(\tilde{e}_t, \tilde{p}_{t-j})}{\sigma_{\tilde{q}}^2} + \frac{C(\tilde{p}_t, \tilde{e}_{t-j})}{\sigma_{\tilde{q}}^2} \right], \tag{4}$$

where $C(\tilde{x}_t, \tilde{y}_{t-j})$ *denotes the covariance* between the first difference of series x at time t and the first difference of series y at lag t-j, and $\sigma_{\tilde{q}}^2$ denotes the variance of the change in the real exchange rate.

The four components in the decomposition given by equation (4)--each of which is 'normalized' by the variance of the change in the real exchange rate--have a relatively straightforward interpretation. The first two components are the autocovariances of changes in the nominal exchange rate and the price levels, respectively. These components measure the amount of autocorrelation in real exchange rate changes induced by the autocorrelation in nominal exchange rate and price level changes. The last two components measure the interaction between changes in nominal exchange rates and relative prices at different lags through the covariances between current and lagged (logarithmic) changes in these variables. Together, the four components measure the contribution of changes in the nominal exchange rate and price levels to changes in the real exchange rate.

III. Econometric Estimates

The spectral densities were estimated for real exchange rates between the U.S. dollar, deutsche mark, Japanese yen, and pound sterling using quarterly data for the period from the first quarter of 1974 to the last quarter of 1989. Nominal exchange rates are measured through end-of-period spot exchange rates while relative prices are measured through consumer price indices. All data were taken from International Financial Statistics.

Some form of approximation is required in the estimation of the spectral density given the infinite number of lagged autocorrelation parameters appearing in equations (1) and (4). 1/ Ideally, the number of lags should be large enough to pick up mean reversion over very long periods, but this has to be weighed against the small number of observations

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1/ The following approach was adopted by Huizinga (1987). (See also Adams and Chadha (1990)). For an alternative approach see Kaminsky (1987).

at long lags. Here, a maximum lag length of 44 quarters, that is 11 years, was used. Given a finite number of autocorrelations, the estimates were then based on constructing the statistic

$$\hat{f}(0) = 2 \sum_{j=1}^{N} w(N,j) \cdot \hat{\rho}_j , \tag{5}$$

where N denotes the number of autocorrelations and w(N,j) represent a set of weights proposed by Newey and West (1987) as given by

$$w(N,j) = (N+1-j)/(N+1). \tag{6}$$

Use of these weights has the effect of giving smaller weight to autocorrelations at long lags.

Figure 1 displays the estimates of the spectral density for real exchange rate changes between the U.S. dollar, the deutsche mark, the Japanese yen, and the pound sterling, along with the decompositions given by equation (4). In each panel of the figure, the estimated values of the spectral density appear on the vertical axis while the number of autocorrelations employed is shown on the horizontal axis. The spectral density is represented by the solid line marked '1', and its components by '2' through '5'. 1/

The estimated spectral densities for the real exchange rates are broadly similar to those presented by Huizinga (1987), Kaminsky (1987) and Adams and Chadha (1990). They show a distinct hump-shaped pattern, first rising above the zero line (suggesting a preponderance of positive autocorrelations at short lags) and then declining below it and approaching (but not reaching) minus unity as negative autocorrelations become more important at longer lags. The hump-shaped pattern is consistent with the possibility of bubbles or self-fulfilling expectations at short lags (see Mussa (1979), Huizinga (1987) and Adams and Chadha (1990)) followed by some tendency toward mean reversion in the very long run. Given that the estimates of the spectral density fall short of minus unity at long lags, however, there is the possibility of both permanent and transitory components in real exchange rate changes. 2/

1/ Each of these lines corresponds to the terms included in equation (4). They are in the order they appear in equation (4).

2/ As noted earlier, there is a basic difficulty in establishing the statistical significance of the estimates given the small number of degrees of freedom at long lags. Hence, while the estimated spectral densities, deviate from the zero line--suggesting that a random walk in real exchange rates might be rejected--the critical regions tend to be very wide. Huizinga (1987) and Adams and Chadha (1990) present estimates of standard errors for the estimates.

As regards the components of the spectral densities, several features are of interest. Most importantly the decompositions suggest that changes in real exchange rates are dominated by the autocovariances of nominal exchange rate changes at all lags, implying that the autocorrelations in real exchange rate changes essentially mirror those in nominal exchange rates. In the cases of the dollar-yen and dollar-pound real exchange rates, however, there is a weak tendency for the spectral density to decline below the nominal exchange rate autocovariance line at very long lags suggesting that the (unobserved) long-run movement in these variables may differ. Second, the autocovariances of price level changes (scaled by the variance of the real exchange rate) shows a tendency to be zero at short lags and then turn positive. These covariances, however, remain close to zero largely as a result of the fact that the variances of real exchange rate changes used to scale them (which are almost equal to the variance of nominal exchange rate changes) are much larger than the variances of price changes. 1/ Third, the covariances of nominal exchange rate changes with lagged price level changes, and of price level changes with lagged nominal exchange rate changes (both scaled by the variance of the change in the real exchange rate) are in most cases approximately equal but opposite in sign, suggesting that their contribution to the negative autocorrelation in real exchange rate changes is essentially zero. Finally, the covariance of relative price changes with lagged nominal exchange rate changes--scaled by the variance of the change in the real exchange rate--is close to zero in the short run but turns negative in the longer run.

In sum, the decompositions suggest that much of the negative autocorrelation in real exchange rate changes is associated with negative autocorrelation in nominal exchange rates, raising the question as to whether empirical exchange rate models imply that any tendency toward mean reversion in real exchange rates should be associated with negative autocorrelation in nominal exchange rates.

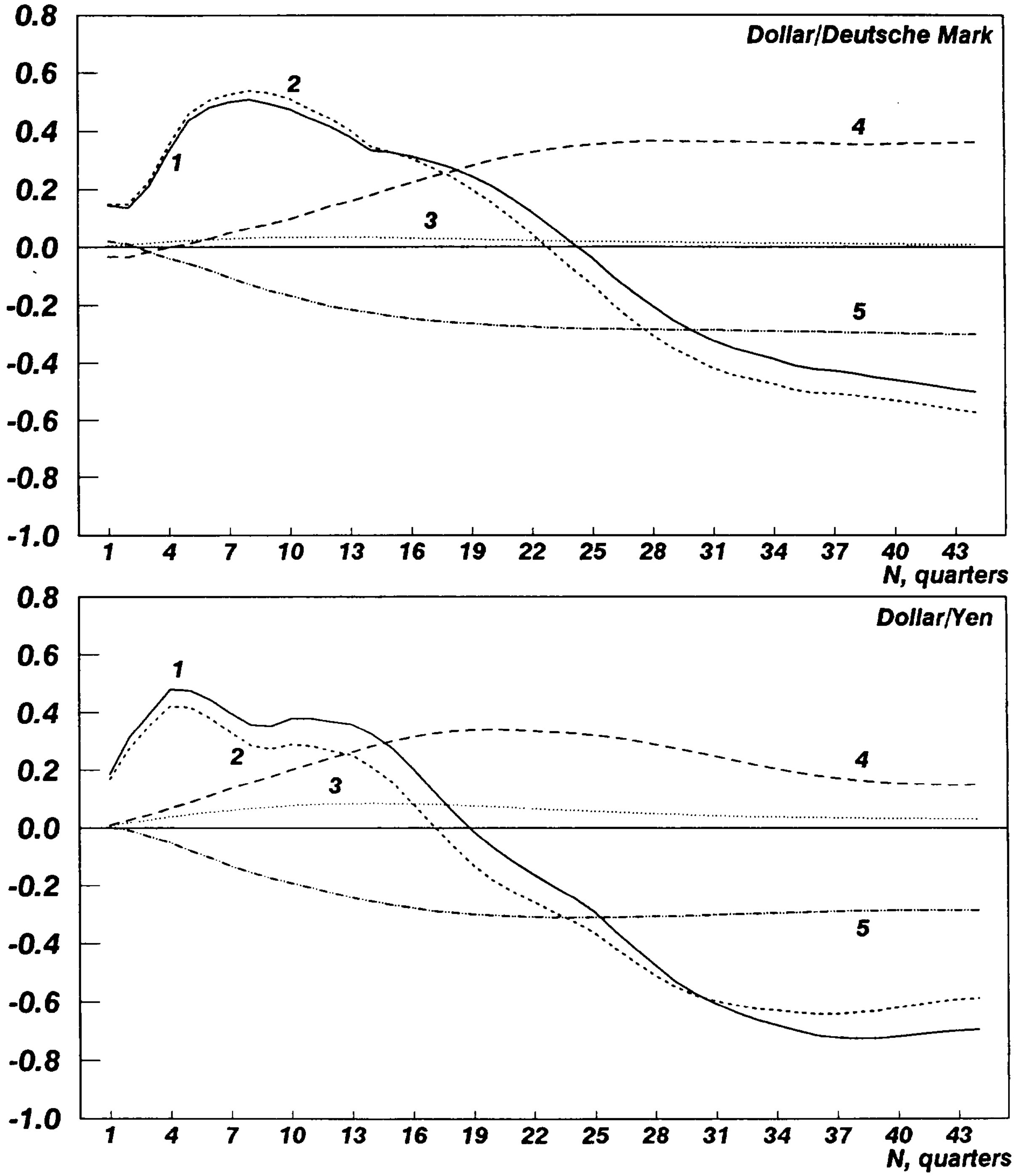
IV. Nominal and Real Shocks and the Exchange Rate

This section reports the spectral densities obtained from stochastic simulations of Dornbusch's overshooting model. Following Adams and Chadha 1991), the model was configured for representative parameter values for the United States and subjected to both nominal and real shocks.

The simulations were conducted using closed-form solutions for the model under the assumptions that the forcing variables--money supply/demand, real aggregate demand shift term, and capacity output--are described by random walks and the system follows the stable arm of the (stochastic)

1/ The quarterly variances of changes in nominal and real exchange rates between major floating currencies since 1974 are essentially equal and could be as large as 70 times the variance of changes in price levels. See Adams and Chadha (1990).

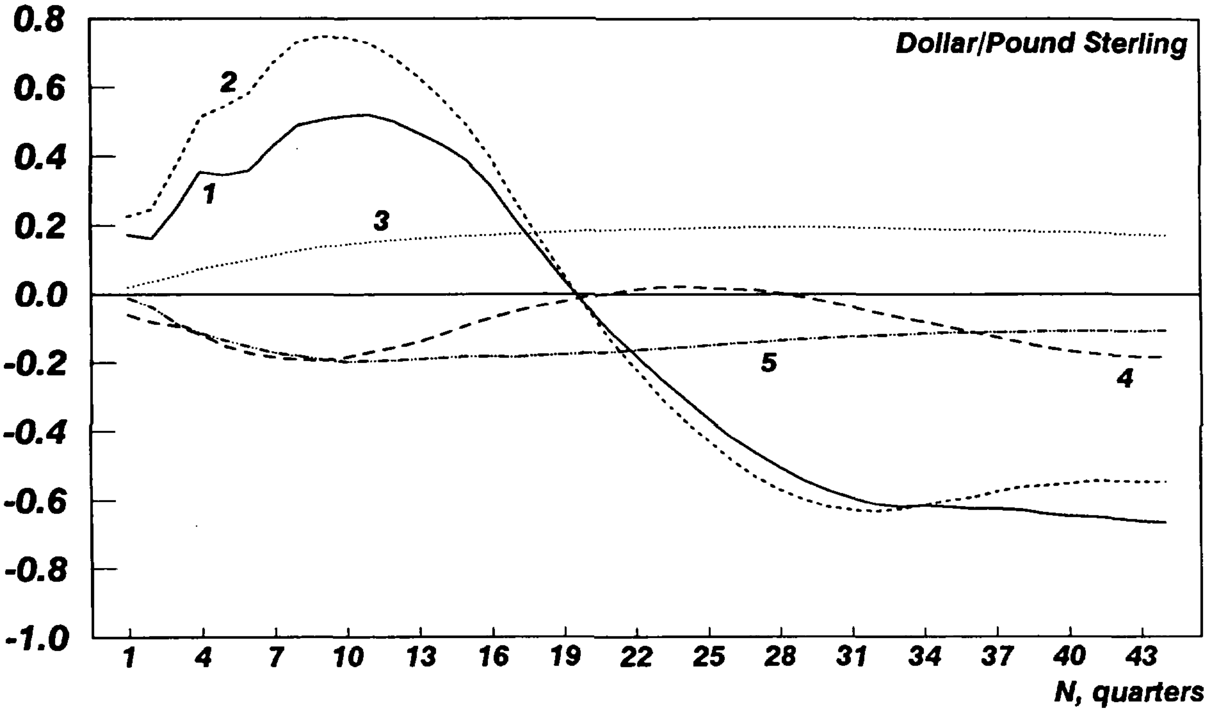
Figure 1. Decomposition of Long-Run Real Exchange Rate Movements of the Dollar. Sample is from 1974,1 to 1989,4, Quarterly.



Note. The plotted values represent twice the sums of the following covariances (at each lag N), normalized by the variance of the real exchange rate:

1. ——— *Real exchange rate changes with own lagged changes;*
2. ········ *Nominal exchange rate changes with own lagged changes;*
3. · · · · · *Relative price changes with own lagged changes;*
4. - - - - *Nominal exchange rate changes with lagged relative price changes;*
5. -·-·-·- *Relative price changes with lagged nominal exchange rate changes.*

Figure 1. (Continued) Decomposition of Long-Run Real Exchange Rate Movements of the Dollar. Sample is from 1974,1 to 1989,4, quarterly.



Note. ***The plotted values represent twice the sums of the following covariances (at each lag N), normalized by the variance of the real exchange rate:***

1. —— ***Real exchange rate changes with own lagged changes;***
2. -------- ***Nominal exchange rate changes with own lagged changes;***
3. ············ ***Relative price changes with own lagged changes;***
4. – – – – ***Nominal exchange rate changes with lagged relative price changes;***
5. –·–·–·– ***Relative price changes with lagged nominal exchange rate changes.***

saddle point. 1/ Representative runs from simulations of the model were then used to construct spectral densities under alternative assumptions about the relative importance of different shocks. Full details on the model, the assumed parameters, and the form of the solutions are provided in the appendix.

Representative values for the spectral densities generated under three different sets of assumptions about the shocks to the model are shown in figures 2-4. Figure 2 illustrates the values of the spectral density for the change in the real exchange rate when there are permanent nominal shocks. Figure 3 is based on a dominance of permanent real aggregate demand shocks interacting with a 'small' one-time innovation in the money supply in the initial period. 2/ Figure 4 displays the values for the spectral density when there are only permanent shocks to capacity output.

The following features of the spectral densities generated by the model are apparent in the case of standard parameter values. 3/

a. Nominal shocks. Apart from the short-run hump (see top panel of figure 2), the spectral density in the case of nominal shocks mirrors most of the features observed in the data. As with the case of the spectral density estimated for the actual data, the simulated spectral density for the change in the real exchange rate is dominated by the change in the nominal exchange rate and it shows a slight tendency to decline below the nominal exchange rate line at very long lags. In addition, as observed in the actual data, the simulated autocovariance line for price level changes, while slightly positive, differs only marginally from the zero line. Interestingly, and consistent with the data, the simulated covariances of relative price and exchange rate changes are essentially equal and opposite in sign in the case of permanent nominal shocks suggesting that their contribution to the negative autocorrelation of real exchange rate changes is offsetting. In addition, each is of the same sign as observed in the actual data for the dollar-deutsche mark and dollar-yen rates.

In order to understand the results, it is useful to recall that a key feature of the Dornbusch model is the tendency for real and nominal exchange rates to overshoot their long-run equilibrium values in response to

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1/ The assumption that the forcing variables follow random walks implies--under the assumption of rational expectations--that all shocks are expected to be permanent. The assumption of permanent shocks was made to avoid difficult issues about the relative importance of transitory and permanent shocks when the main focus is on the response to given shocks as implied by the intrinsic dynamics of the model.

2/ The small monetary shock was introduced to prevent the variance of changes in the price level from going to zero.

3/ The effects of varying the degree of price stickiness are discussed below.

(permanent) nominal shocks. 1/ Under these conditions, nominal and real exchange rates contain sizable transitory components leading to negative autocorrelation in their changes and a spectral density that is below zero. The value to which the spectral density converges in the case of permanent nominal shocks--which provides a measure of the ratio of the variance of the change in the permanent component of the real exchange rate to the variance of its total change--is minus unity since nominal shocks have no permanent effects on real variables. 2/ The value to which the nominal exchange rate changes line converges, on the other hand, measures the size of the permanent movements in the nominal exchange rate, which is determined by the degree of overshooting relative to the longer-run or permanent movement in the nominal exchange rate. The parameter values employed (see appendix) imply that a 1 percent positive nominal shock leads on impact to a 5 percent depreciation of the exchange rate, overshooting its long-run response of 1 percent. 3/ Squaring these magnitudes to obtain measures of variance, it follows that the ratio of permanent to total movements is (1/25) or 0.04, so that the nominal exchange rate line should decline to approximately -0.96.

As regards the behavior of the other components of the spectral density, the autocovariances of price changes will be positive because, as a result of price stickiness, changes in the price level are positively correlated; 4/ the closeness of the line to zero results from this measure being normalized by the variance of changes in the real exchange rate which far exceeds that of changes in the price level. 5/

b. Real shocks. Unlike the case of purely nominal shocks, permanent real shocks to demand and supply call for long-run changes in the real exchange rate and for permanent deviations from purchasing power parity. The two real shocks which were simulated differ, however, according to whether the required change in the long-run real exchange rate is brought

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1/ Overshooting of the nominal exchange rate in response to permanent nominal shocks need not occur in generalizations of the Dornbusch model that include a broadly based price index in the money demand function and endogenous output. (See Dornbusch (1976)). Overshooting does occur in the version of the model used in the simulations of this paper (see appendix).

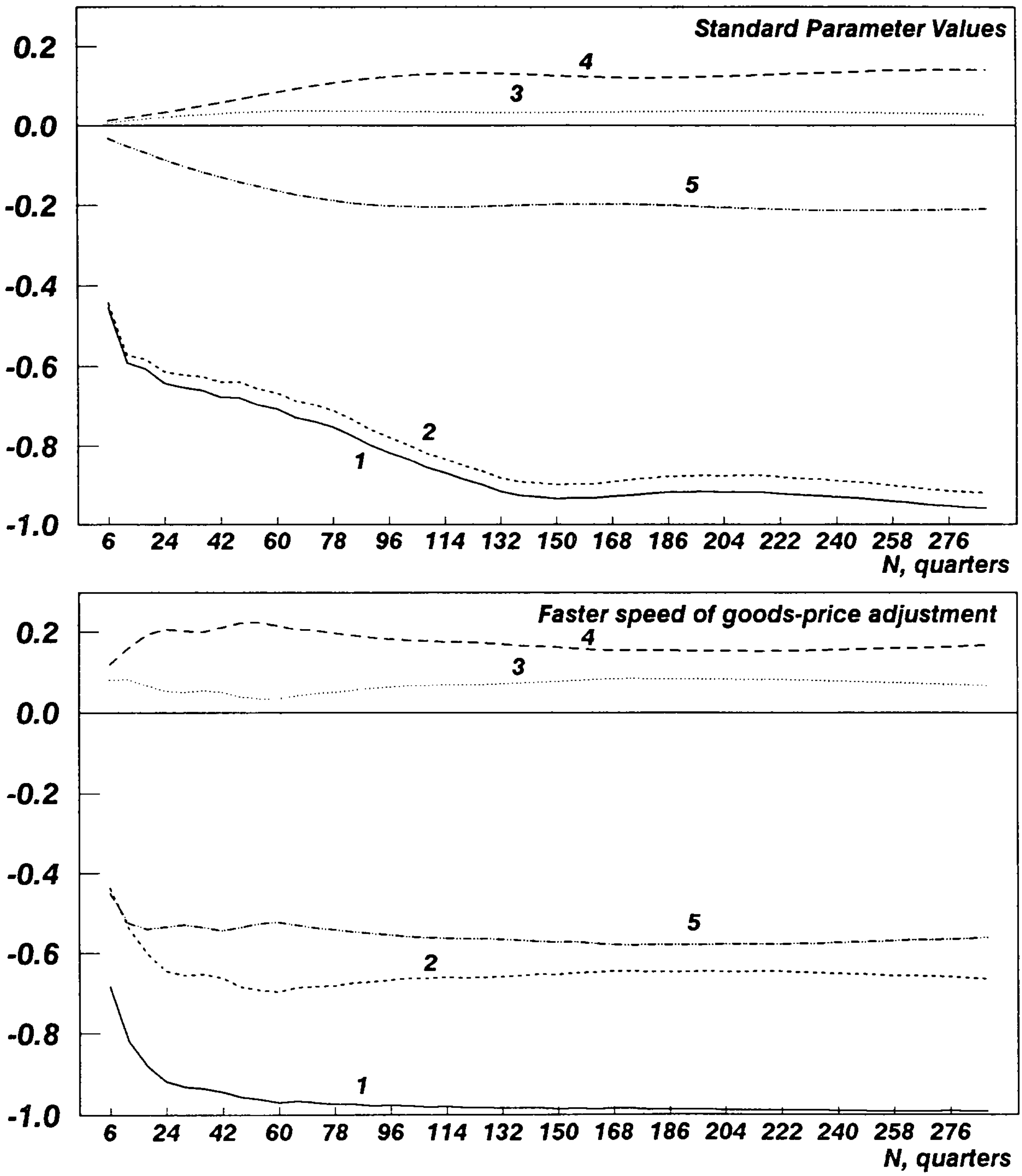
2/ Recalling equation (2), the ratio is obtained by adding the estimated long-run value of f(0) to unity. In this case the estimated value of f(0) is zero.

3/ Strictly speaking, for the line to measure the permanent movements in the nominal exchange rate, the autocovariances should be divided by the variance of nominal rather than real exchange rate changes. As a practical matter, however, the two are almost identical under our assumptions (see Adams and Chadha (1991)).

4/ This is not to argue that price level stickiness implies inflation stickiness. However, as shown in Chadha (1989), in response to a permanent shock, inflation rates will be positively correlated over time.

5/ A feature also observed in the actual data.

Figure 2. Decomposition of Long-Run Real Exchange Rate Movements for Data from Simulations of Dornbusch Model Subject to Monetary Shocks. Typical Runs.



Note. The plotted values represent twice the sums of the following covariances (at each lag N), normalized by the variance of the real exchange rate:

1. —— Real exchange rate changes with own lagged changes;
2. ········ Nominal exchange rate changes with own lagged changes;
3. ·· ·· ·· Relative price changes with own lagged changes;
4. – – – – Nominal exchange rate changes with lagged relative price changes;
5. -·-·-·- Relative price changes with lagged nominal exchange rate changes.

about predominantly by changes in the nominal exchange rate or by changes in price levels (or both), with important implications for the decomposition of the spectral density for the change in the real exchange rate.

In the case of permanent shocks to real aggregate demand (see figure 3) the spectral density for the change in the real exchange rate mirrors exactly the change in the nominal exchange rate. This is because in this case the required change in the real exchange rate is brought about entirely through changes in the nominal exchange rate. In contrast to the case of purely nominal shocks, however, the spectral density does not approach minus one because there are permanent changes in the long-run equilibrium real exchange rate. Moreover, in contrast to the case(s) of nominal shocks (and the actual data), all of the other covariance terms are essentially zero in this case because domestic prices do not need to change to bring about the required change in the real exchange rate. Permanent real demand shocks can therefore account for the high correlation between nominal and real exchange rates but not for the other components of the spectral density and cannot explain the very large temporary changes in the real exchange rate suggested by the actual data.

In the case of permanent shocks to capacity output or aggregate supply (see top panel of figure 4), the spectral density differs markedly from that observed in the actual data. The spectral density function for the change in the real exchange rate in this case has a slight hump-shaped pattern but tends to be positive at all lags. This case represents the polar opposite to the case of nominal shocks, and the positive autocorrelations result from the fact that the exchange rate undershoots its long-run value in response to innovations in capacity output. Also, because the required change in the real exchange rate in this case is brought about by changes in both price levels and the nominal exchange rate--which differ in the magnitude of their long-run responses--the spectral density for the real exchange rate and the line representing the contribution of nominal exchange rate autocorrelations do not move closely together.

In order to illustrate the effects of alternative degrees of price stickiness, the bottom panels of figures 2 and 4 show the spectral densities obtained in the cases of the nominal and capacity output shocks when prices adjust much more rapidly. 1/ (The spectral density that obtains in the case of the real demand shock is independent of the degree of price stickiness since, as noted earlier, the entire adjustment occurs through the nominal exchange rate; the spectral density with a faster speed of goods price adjustment is, therefore, not presented in figure 3). The degree of price stickiness has two related effects on the simulations. First, it influences the speed with which the system approaches equilibrium following any shock with adjustment occurring more rapidly the faster prices adjust. Second, it has implications for the amount of over or under shooting in response to a given shock. As a result, in the case of the nominal shock,

1/ See the appendix for details of the simulations.

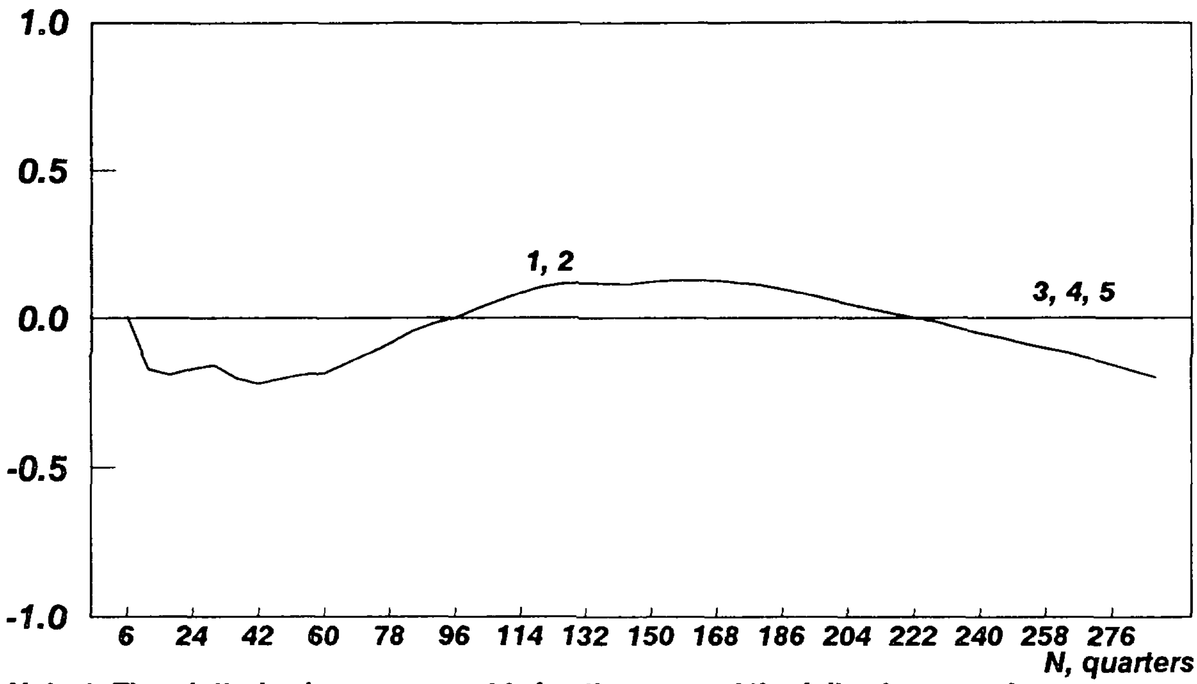
the real exchange rate approaches the long-run equilibrium faster and by 44 quarters the spectral density for the change in the real exchange rate is for practical purposes minus unity. In addition, the nominal exchange rate has a smaller temporary component (i.e., it overshoots by less) the more flexible are prices, implying that the autocovariance of nominal exchange rate changes line tends toward a larger (less negative) number than when prices are less flexible. Together, these two tendencies result in the distance between the nominal and real exchange rate changes lines becoming quite large (see lower panel of figure 2). The implications of faster price adjustment in the case of capacity output shocks is more difficult to interpret. From the bottom panel of figure 4, it is apparent that the major implication is that the amount of positive autocorrelation in real exchange rate changes is reduced as a result of prices adjusting faster to their long-run equilibrium level.

V. Conclusions

This paper has shown that when estimates of the spectral density for changes in real exchange rates are decomposed into components associated with changes in nominal exchange rates and changes in price levels much of the long-run negative autocorrelation in real exchange rate changes stems from negative autocorrelations in nominal exchange rate changes. Stochastic simulations of a simplified version of the Dornbusch model subjected to permanent nominal shocks were shown to produce estimates for the spectral density for real exchange rate changes that could rationalize these negative correlations. In particular, the simulations of the effects of permanent nominal shocks gave rise to large transitory components in real and nominal exchange rates and a close association between the autocorrelations in these rates in the short and the longer run but, not of course, in the very long run. In addition, they could reproduce several other features of the temporal correlations between nominal exchange rate and relative price changes. The simulations of the effects of real shocks on the other hand produced densities for changes in real exchange rates that differed markedly from those observed in the data.

While the results cannot of course establish the importance of nominal shocks, we nevertheless feel that they are suggestive of a potential role for such shocks and the intrinsic dynamics implied by a sticky-price monetary model.

Figure 3. Decomposition of Long-Run Real Exchange Rate Movements for Data from Simulations of Dornbusch model subject to Real Demand Shocks. Typical run.



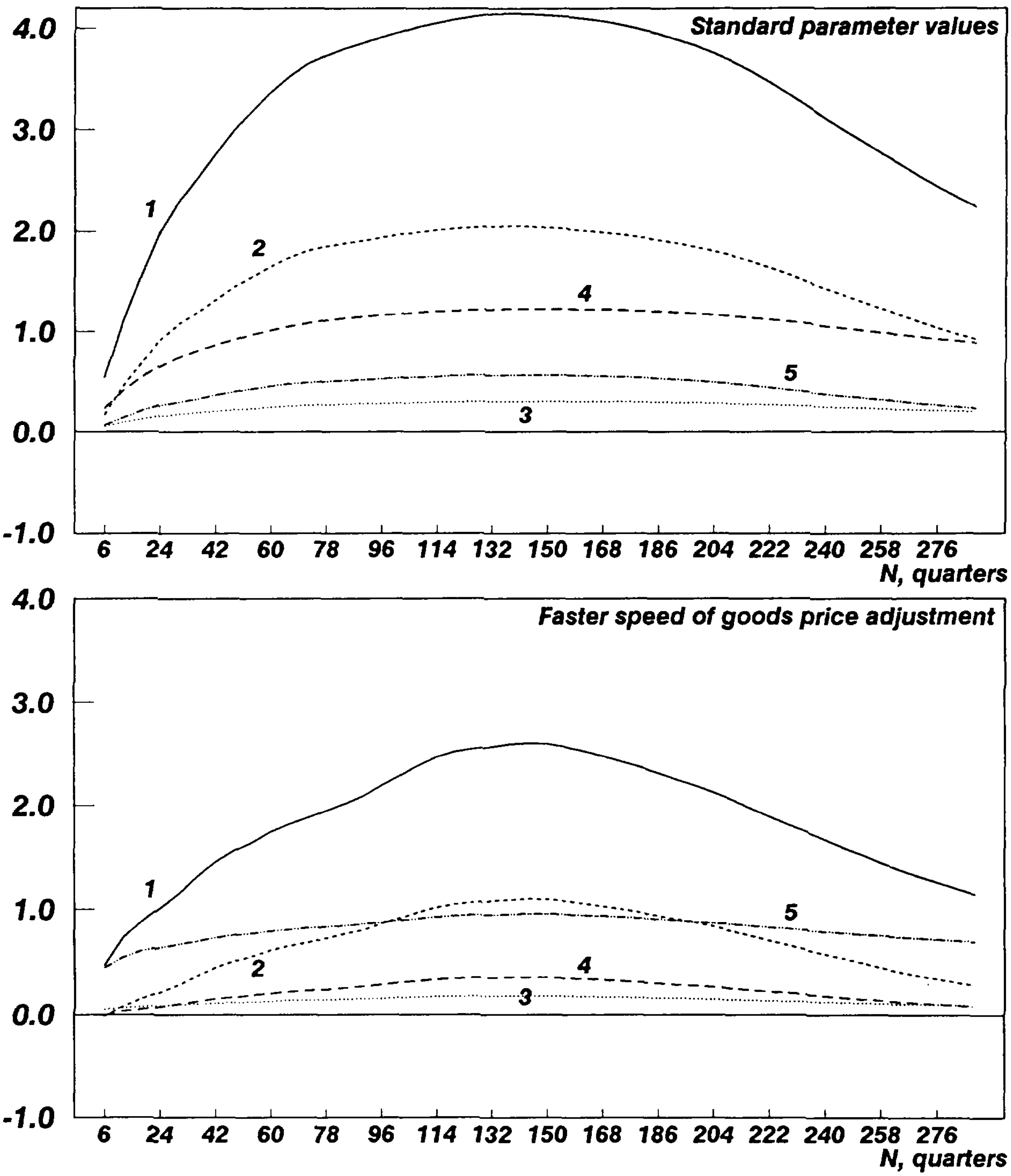
Note 1. The plotted values represent twice the sums of the following covariances (at each lag N), normalized by the variance of the real exchange rate:

1. ——— *Real exchange rate changes with own lagged changes;*
2. ········ *Nominal exchange rate changes with own lagged changes;*
3. ·············· *Relative price changes with own lagged changes;*
4. - - - - *Nominal exchange rate changes with lagged relative price changes;*
5. -·-·-·- *Relative price changes with lagged nominal exchange rate changes.*

Note 2. The simulations include a small monetary shock in the initial period to prevent the variance of changes in the price level being degenerate.

Note 3. The results are identical for alternative degrees of price stickines since the entire adjustment occurs through the nominal exchange rate.

Figure 4. Decomposition of Long-Run Real Exchange Rate Movements for Data from Simulations of Dornbusch Model Subject to Supply Shocks. Typical Runs.



Note. The plotted values represent twice the sums of the following covariances (at each lag N), normalized by the variance of the real exchange rate:

1. ——— *Real exchange rate changes with own lagged changes;*
2. -------- *Nominal exchange rate changes with own lagged changes;*
3. ·········· *Relative price changes with own lagged changes;*
4. – – – – *Nominal exchange rate changes with lagged relative price changes;*
5. –·–·–·– *Relative price changes with lagged nominal exchange rate changes.*

The basic version of the original model developed by Dornbusch(1976) is used for the simulations. 1/ The model is described by equations (A1)-(A5) where all variables other than interest rates are measured in natural logarithms and foreign variables are distinguished from domestic variables by an asterisk(*).

$$M_t - P_t = \beta \cdot \bar{y}_t - \alpha \cdot R_t \tag{A1}$$

$$R_t = R^*_t + E_t e_{t+1} - e_t \tag{A2}$$

$$P_{t+1} - P_t = \phi \cdot (y_t - \bar{y}_t) \tag{A3}$$

$$y_t = \theta \cdot q_t + S_t \tag{A4}$$

$$q_t = e_t + (P^*_t - P_t) = e_t + p_t \tag{A5}$$

Equation (A1) describes equilibrium in the domestic money market in terms of equality between the stock supply and demand for money (M); money demand is assumed to depend positively on capacity output ($\bar{y}$) 2/ and negatively on the domestic interest rate (R). Equation (A2) describes uncovered interest rate parity, with the domestic interest rate equal to that abroad, R^*, adjusted for the expected rate of depreciation of the nominal exchange rate ($E_t e_{t+1} - e_t$). 3/ Equation (A3) is a simple Phillips curve relating domestic inflation ($P_{t+1} - P_t$) to the gap between actual (y) and capacity output ($\bar{y}$); by construction, the domestic price level is predetermined in the current period. 4/ Finally, equation (A4) specifies that the demand for domestic output depends positively on the real exchange rate (q) as defined in equation (A5), and a real demand shock S_t; the real exchange rate is measured as the difference (p) between foreign (P^*) and domestic prices (P), adjusted for the nominal exchange rate.

1/ See Obstfeld and Stockman (1985) for a discussion of some of the refinements and extensions to the model that have subsequently been made.

2/ The assumption that money demand depends on capacity rather than actual output is made implicitly by Dornbusch (1976) in the version of the model described in the main part of his paper.

3/ The information set is assumed to include the model as well as the current and lagged values of all variables.

4/ Problems with this particular price adjustment rule--which is the rule used by Dornbusch (1976)--are discussed by Obstfeld and Rogoff (1984). The problematic properties arise particularly with respect to anticipated shocks. They are less of a concern here, since all shocks are unanticipated and permanent. For a version of the Dornbusch model with rational staggered contracts, see Chadha (1987).

The money supply, the exogenous real demand shift term, and capacity output are assumed to follow random walks

$$M_t = M_{t-1} + \epsilon_t , \quad \text{where } \epsilon_t \sim iid(0,\sigma_\epsilon^2) , \tag{A6}$$

$$S_t = S_{t-1} + \Omega_t , \quad \text{where } \Omega_t \sim iid(0,\sigma_\Omega^2) , \tag{A7}$$

$$\bar{y}_t = \bar{y}_{t-1} + \eta_t , \quad \text{where } \eta_t \sim iid(0,\sigma_\eta^2) , \tag{A8}$$

so that all changes in them are unanticipated and expected to be permanent. In addition it is assumed that their innovations are uncorrelated.

Solutions to the model under the simplifying assumption that all foreign variables are constant and (their logarithms) equal to zero are considered. Equations (A1)-(A5), along with the assumed processes generating the exogenous variables in (A6)-(A8) can then be combined to yield a pair of first-order stochastic difference equations in the nominal exchange rate and the price level. For standard parameter values, one of the two roots of this system will lie outside the unit circle and the other inside it. Under these conditions, as in Dornbusch's original model, the long-run equilibrium is a saddle point. The economy is assumed to be on the stable arm of this saddle point, implying that the solutions to equations (A1)-(A5) are 1/

$$P_t = \lambda \cdot P_{t-1} + (1-\lambda) \cdot M_{t-1} - (1-\lambda) \cdot \beta \bar{y}_{t-1} , \tag{A9}$$

$$e_t = -\frac{1}{\alpha(1-\lambda)} \cdot P_t + \left[1 + \frac{1}{\alpha(1-\lambda)}\right] \cdot M_t - \frac{1}{\theta} \cdot S_t + \frac{\phi - \beta(1-\lambda)}{\phi\theta} \cdot \bar{y}_t , \tag{A10}$$

$$\text{where } \lambda = 1 - \frac{\phi\theta}{2} - \frac{1}{2}\left[\phi^2\theta^2 + \frac{4\phi\theta}{\alpha}\right]^{1/2} , \tag{A11}$$

refers to the (assumed) stable eigenvalue of the system.

Several features of the solutions in (A9)-(A10) are noteworthy.

(a) Even though the exogenous processes follow random walks with all changes expected to be permanent, the endogenous nominal variables--spot exchange rates and nominal prices, and hence real exchange rates--will in general contain systematic components as a result of the intrinsic dynamics

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1/ It is straightforward to derive the solutions for the real exchange rate, the interest rate, and output from the following equations.

of the model arising from the assumption of sluggish goods price adjustment. 1/ (See Adams and Boyer (1986))). These endogenous variables therefore have both permanent (random walk) and transitory (stationary) components.

(b) In response to innovations in the money supply, the nominal exchange rate overshoots its long-run value on impact. In response to an innovation in the real demand shift term, the nominal exchange rate will jump immediately to it's new long-run value. An innovation in real capacity output, on the other hand, would result in the exchange rate undershooting its long-run value on impact.

The model was simulated using the random generator on RATS with numerical values for the parameter vector [α, β, θ, ϕ] and the assumption that the innovations in the forcing variables have a 1 percent standard deviation. Rather than perform the simulations on wide ranges of alternative parameter values, for purposes of empirical relevance representative values for the United States were chosen. The parameters were selected to be consistent with data at a quarterly frequency.

For the (absolute) value for the semi-interest elasticity of money demand (α) a value of 4 was used. At an (average) annual interest rate of 8 percent (the average short-term interest rate in the United States during the first half of 1990) this parameter gives a relatively small (quarterly) interest elasticity of money demand of -0.08, which is at the mid-point of Friedman's (1978) range for the elasticity of M1 demand with respect to short-term interest rates. This value is also consistent with the money demand elasticity referred to by Mussa (1984) in his survey of models of exchange rate determination. The elasticity of money demand with respect to output (β) was set at unity.

The parameter θ, which measures the (reduced-form) elasticity of aggregate demand with respect to the real exchange rate, was assumed to equal 0.25. Unlike the other parameters, there are few direct estimates of this parameter available in the literature. A value of 0.25, however, appears fairly neutral and is not grossly at odds with comparable parameters in several large econometric models.

The price stickiness parameter, ϕ, which plays a key role in the simulations, was assumed to equal 0.05 on quarterly data. This value is consistent with estimates of price stickiness made for the United States by

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1/ If the only shocks to the system are real demand shocks and the price level is at it's steady-state value (which is independent of the real demand shift term) then there will be no intrinsic dynamics.

Taylor (1980) 1/ and Rotemberg (1982); 2/ it implies that around 20 percent of the gap between actual prices and their flexible equilibrium solution is made up in one year. While this is obviously low when judged against flexible price models, it is clearly not at odds with the view that there is considerable price inertia in the United States. This parameter value is denoted 'standard' in figures 2-4 in the text. Simulations were also carried out for a considerably faster speed of goods price adjustment, with ϕ set at 0.95.

Based on the representative parameter values, the solutions to the Dornbusch model are characterized by one root equal to 0.9375 and the other equal to 1.05, implying that the long-run equilibrium is a saddle point. The parameter values imply that a 1 percent increase in the money supply leads to a 5 percent depreciation of the nominal and real exchange rate on impact. Simulations were carried out for sample periods of 400 quarters with three different assumptions about the shocks to which the system was subject: (i) monetary shocks only; (ii) real demand shocks and, so as to prevent the variance of the price level from becoming zero, a nominal shock in the initial period; (iii) innovations in real capacity output only. A representative run was then picked and the spectral density and its components plotted in figures 2-4.

1/ Taylor (1980) estimates the response of "new" wage contracts to excess demand as 0.087 on a quarterly basis. Since in his framework only a subset of wage/price setters revise their prices in each period, our value of 0.05 for the responsiveness of the aggregate price level seems appropriate.

2/ Rotemberg (1982) jointly estimates a system of price, output, and money equations with a reduced-form equation for the general price level very similar to the solution for the general price level obtained in equation (A9). His preferred estimates for the coefficient on the lagged aggregate price level lie between 0.92 and 0.946; this coefficient corresponds to the stable characteristic root, λ, of our system and is equal to 0.9375 (see below). For further details see Rotemberg (1982) and Chadha (1989).

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