New Evidence Connecting Exchange Rates to Business Cycles

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Virtually every theoretical model of exchange rates predicts that the real exchange rate between two countries (with floating nominal exchange rates) is correlated with the ratio of business-cycle conditions in the two countries. Yet almost no empirical evidence exists to support this prediction of the models. In fact, there is little empirical evidence that ties real exchange rates to *any* underlying economic conditions. Some well-known studies have concluded that exchange rates appear to have "a life of their own," perhaps moving with speculators' expectations far more than with changes in economic fundamentals. (See Flood and Rose [1995] for a prominent example.)

Contrary to this widely held contention, this article presents new evidence that exchange rates *are* connected with fundamentals, in particular with the relative gross domestic product (GDP) of each of the two countries involved, as predicted by nearly all exchange-rate theories. Moreover, they are related in the direction predicted by standard models: a country's currency tends to be depreciated in real terms when that country's real GDP is relatively high, and vice versa.

Why have previous studies not found this relationship between real exchange rates and ratios of real GDP? The answer is that the relationship is hard to detect with simple linear models, because it appears to be nonlinear and conditional on persistent movements (rather than purely transitory movements) in the data. Recent theoretical and empirical work has pointed to the potential

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importance of nonlinearities in exchange-rate data and has pointed the way to the evidence reported here.

1. WHAT THEORETICAL MODELS SAY

A common feature of nearly all models of exchange rates is the prediction that the real exchange rate between two countries is correlated with the real-GDP ratio between them.[1] Define the real exchange rate as the exchange-rate-adjusted ratio of price levels: if the nominal exchange rate e is the price of foreign money (in units of home money) and if P and P^* are the home and foreign price levels, then the real exchange rate is $q \equiv eP^*/P$. The real exchange rate measures the relative price of a basket of foreign goods in terms of a basket of home goods.[2] An increase in q means "real depreciation" of home currency (a decrease in the relative price of home goods); a decrease in q means "real appreciation" of home currency (an increase in the relative price of home goods). Define the output ratio y as home real GDP divided by foreign real GDP. Most theoretical models of exchange rates predict a positive relationship between y and q.

The economic reasoning behind this prediction is not difficult, though its details differ depending on the model. First, consider an equilibrium model of exchange rates as outlined in Stockman (1987). The real exchange rate in that model, as in other equilibrium models[3] and some sticky-price models,[4] equals the marginal rate of substitution (MRS) in consumption between home and foreign goods. Consider a model with two countries and two goods, one produced exclusively in each country. A representative consumer in the home country has the utility function $U(x, y)$, where x and y represent consumption of home and foreign goods by consumers in the home country. A representative consumer in the foreign country has the utility function $U^*(x^*, y^*)$, where x^* and y^* represent consumption of home and foreign goods by foreign consumers. Regardless of many other details of a model like this, an equilibrium will usually entail a condition that says

$$MRS(x, y) = MRS^*(x^*, y^*) = 1/q, \tag{1}$$

where

$$MRS(x, y) = U_X(x, y)/U_Y(x, y) \tag{2a}$$

[1] Some models, such as in Stockman and Tesar (1995), do not necessarily make this prediction because they postulate demand shocks with flexible prices.

[2] The baskets of goods are the baskets used to measure the price indexes P and P^*.

[3] See, for example, Stockman (1980, 1987), Lucas (1982), and Svensson (1985).

[4] See, for example, Obstfeld and Rogoff (1995) and Kollmann (1997). The equilibrium differs in other models, such as in Chari, Kehoe, and McGrattan (1998).

and

$$MRS^*(x^*, y^*) = U_X^*(x^*, y^*)/U_Y^*(x^*, y^*) \tag{2b}$$

are the equilibrium marginal rates of substitution between home and foreign goods, X and Y, for the home and foreign consumers. The difference between the operations of most models with flexible or sticky prices lies in the behavior of the consumptions, x and y, *inside* the MRS function. Short-run price stickiness affects consumption, so it affects the real exchange rate q.

First consider a model with flexible prices and suppose that production of the home good, X, rises exogenously, holding fixed the production of the foreign good, Y. This rise in the supply of the home good typically reduces its equilibrium relative price; i.e., it typically depreciates the home real exchange rate (it raises q). Therefore a rise in the ratio of home-country output to foreign-country output is associated with home-currency real depreciation.

A simple example occurs when the utility functions are the same in both countries and the elasticity of substitution between home and foreign goods is unity. Then a 10 percent increase in production of X reduces its relative price by 10 percent in equilibrium, and consumers in each country increase their consumption of X by 10 percent and leave their consumption of Y unchanged.[5] With any standard utility function, an increase in x, holding y fixed, reduces $MRS(x, y)$ and thereby causes home real depreciation (a rise in q).[6] This discussion has assumed that home output rises exogenously with no change in foreign output. However, the same reasoning and results apply when home and foreign

[5] This occurs regardless of the asset market structure of the model—the result holds with complete asset markets or no asset markets at all. See Stockman (1987) and Cole and Obstfeld (1991). More generally, whether the increase in supply of X raises or reduces home consumption of the foreign good Y depends on details of the model. For example, if the elasticity of substitution between the two goods is very low, then the demand for X may be very inelastic, and a 10 percent increase in the supply of X may reduce its price so much that home consumers reduce consumption of Y.

[6] The implication in this example that home output rises relative to foreign output may appear to depend on the use of different units of measurement for the two outputs—with home output measured in units of the home good X and foreign output measured in units of the foreign good Y. However, the model continues to predict a positive relationship between the output ratio and the real exchange rate if both outputs are expressed in common units, as long as the elasticity of substitution between the goods is less than unity (so that demands for the goods are elastic). For example, suppose both are measured in units of the home good X. The value of foreign output, measured in units of the home good X, is qy^s, where y^s denotes foreign output of good Y. Letting x^s denote home output of good X, the ratio of home-to-foreign output, expressed in common units, is x^s/qy^s. With unit-elastic demands, this ratio stays constant as x^s and q move together. When demands are less than unit-elastic, this ratio rises and falls together with x^s and q. So units of measurement of the output ratio become an important issue only if demands are elastic. This article uses national GDP data with each country's real GDP expressed in units of its own production bundle to calculate the output ratio y, so this measurement issue does not apply. However, the measurement issue would become important if a similar analysis calculated the output ratio with an exchange-rate-adjusted ratio of nominal GDP series.

output move together (as in the data) with output in one country exogenously rising more than output in the other country.[7]

Not surprisingly, the model's implication for comovements of the output ratio and the real exchange rate is *reversed* for exogenous changes in demand. After all, changes in supply generate negative comovements of the output of a good and its price; changes in demand generate positive comovements. For various reasons, most models of exchange rates of the type discussed above have relied on productivity shocks rather than demand shocks to drive the model.[8] This reliance results partly from the relative success of real business-cycle models driven by technology shocks and partly from the difficult task of identifying demand shocks in the data. (Fiscal policy changes appear to be much too small and infrequent in the data to explain either business cycles or exchange-rate changes; taste shocks are inherently unobservable, though potentially measurable through their effects on the economy.)

Despite the small role of demand shocks in flexible-price models, they have played the key role in another class of models—those with sluggish nominal price adjustment. These models predict, even with demand shocks, that output ratios and real exchange rates are positively correlated—a rise in home output relative to foreign output (a rise in y) occurs together with real depreciation of home currency (a rise in q). Again, the basic economic reasoning is straightforward and robust to many perturbations of details in the models.

When prices are sticky in the short run, a vast array of business-cycle models generates the prediction that an increase in aggregate demand raises real output in the short run. Corresponding models of open economies also predict short-run home-currency depreciation (the nominal exchange rate, e, rises), which translates into *real* depreciation (an increase in q) because of sticky prices. Together, these two results imply that aggregate demand shocks create a positive relationship between the output ratio y and real exchange rate q.

Despite differences in detail across sticky-price models, the reasons for their exchange-rate predictions share a common feature: in each model, the exchange rate is determined through an uncovered-interest-parity condition.

[7] This basic logic is not sufficient to generate an unambiguous prediction for the balance of trade or the current account of the balance of payments, as Stockman (1990) explains. To see why, imagine first that the increase in home production is temporary and that nothing that people do can make it permanent. In that case, people in the home country will typically want to save a large fraction of this temporary increase in income, and they will save by lending to (investing in) people in foreign countries. This international lending creates a surplus in the balance of trade and the current account. Now suppose instead that the increase in home production can be made permanent (or at least longer lasting) through investment to expand the economy's capital stock. In this case, investment demand rises and the equilibrium increase in investment (in the short run) may exceed the equilibrium increase in production; if so, the economy runs a deficit in its trade balance and current account.

[8] See Stockman and Tesar (1995) for a counterexample.

Uncovered interest parity says that the expected rate of change of the *nominal* exchange rate equals the difference in nominal interest rates across countries. This condition derives from two components: (1) the arbitrage condition of covered interest parity, which states that the forward exchange rate relative to the spot exchange rate equals the difference in interest rates (and which is well substantiated in the data), and (2) the hypothesis that the forward exchange rate equals the expected future spot exchange rate. The second component, unlike the first, appears to be falsified in the data for reasons that economists do not yet understand.[9] Its falsification does not necessarily invalidate theories that use it as a component (any more than quantum effects invalidate Newtonian physics) because the violations (which appear to be either time-varying risk premia or systematic forecast errors) could be small enough that they do not materially affect the theory.

The common reasoning in these models states that the increase in aggregate demand (perhaps resulting from a monetary shock) depreciates the expected *future* nominal exchange rate. Given the difference in nominal interest rates across countries, uncovered interest parity then requires a corresponding depreciation of the *current* nominal exchange rate. In some models, such as in Obstfeld and Rogoff (1995), the shock to aggregate demand does not affect the interest differential, so the current nominal exchange rate immediately depreciates to its expected long-run level.[10] In other models, such as in Dornbusch (1976) or Chari, Kehoe, and McGrattan (1998), the shock to aggregate demand reduces the home nominal interest rate relative to the foreign rate, requiring a short-run depreciation in excess of the long-run depreciation. In both cases, nominal depreciation implies real depreciation (a rise in q) in the short run because of sticky prices.[11] As a result, the models imply a positive correlation between the output ratio y and real exchange rate q.[12]

[9] With exchange rates expressed in logarithms, arbitrage would make this second component true in a world without uncertainty. Froot and Thaler (1990) discuss the puzzle of empirical falsification of this component.

[10] In the Obstfeld-Rogoff model, for example, the short-run response of the output ratio is proportional to the short-run response of the nominal and real exchange rates, with the factor of proportionality determined by the elasticity of substitution in consumption between various goods.

[11] Even a model in which the nominal interest rate rises in the short run (because the expected-inflation effect of a monetary shock exceeds the fall in the real interest rate) would predict currency depreciation if the increase in the home nominal interest rate were smaller than the percentage increase in the long-run exchange rate.

[12] For reasons similar to those explained in footnote 7, these models do not make unambiguous, robust predictions about the response of the trade balance or current account, or about comovements between these and other variables.

2. EMPIRICAL METHODS AND RESULTS

Data for the models consist of quarterly observations on exchange rates and real GDP for Australia, Canada, France, Italy, Japan, the Netherlands, Spain, Switzerland, the United Kingdom, and the United States, generally over the period 1974:1 through 1996:4. These countries appear in the sample as representative of developed economies with some heterogeneity in geography and circumstances, yet with consistent and reliable data. Germany is notable for its absence in the sample. Its exclusion is due to data issues associated with unification, which could play a particularly important role with our short sample of less than 25 years per country.

Define the nominal exchange rate e_{ab} as the domestic price in country a of the (foreign) currency of country b, and q_{ab} as the (natural) logarithm of the relative price of country b's goods in terms of country a's goods:

$$q_{ab} = \ln\left(\frac{e_{ab}p_b}{p_a}\right).$$

An increase in q_{ab} indicates "real depreciation" of currency a and "real appreciation" of currency b. Define y_{ab} as the (natural) logarithm of the ratio of output in country a relative to country b:

$$y_{ab} = \ln\left(\frac{GDP_a}{GDP_b}\right),$$

where GDP_a indicates real GDP in country a.

As noted above, standard models with sticky prices, such as in Dornbusch (1976) and its variants, including Obstfeld and Rogoff (1995) and Chari, Kehoe, and McGrattan (1998), imply a *positive* relationship between q_{ab} and y_{ab}. Specifically, a monetary expansion in country a raises y_{ab} (above its long-run equilibrium value) and raises q_{ab} (that is, it causes real depreciation of currency a).

Simple correlations are not consistent with this prediction. For example, simple correlations between q_{ab} and y_{ab} appear in Table 1, with the United States as the comparison country for each exchange rate. They are negative in seven out of eight cases. Only the correlation for Switzerland takes the predicted positive sign, and that correlation is smaller than the absolute values of four of the seven negative correlations.

While most empirical economic research involves linear methods, recent empirical and theoretical work motivates an alternative nonlinear approach to the data. Recent empirical papers present evidence of nonlinearities in univariate time-series models of exchange rates.[13] These papers examine nonlinear models of exchange rate adjustment toward purchasing-power-parity levels

[13] See O'Connell (1997); O'Connell and Wei (1997); Michael, Nobay, and Peel (1997); Obstfeld and Taylor (1997); and Taylor and Peel (1997).

Table 1 Simple Correlations

Italy	−0.48
Japan	−0.62
U.K.	−0.23
France	−0.49
Switzerland	0.38
Spain	−0.15
Netherlands	−0.80
Australia	−0.17

when adjustment takes place only or mainly outside a band around the long-run level of the exchange rate or when adjustment is simply more rapid because exchange rates begin farther from their long-run levels. Recent evidence strongly indicates nonlinearities in exchange-rate behavior, with faster mean reversion in exchange rates when they begin far from purchasing-power-parity levels. This result means that the half-life of real exchange rates (the time it takes them to return to their long-run levels following a one-time shock) is apparently lower than previous research had indicated. Whether the half-life is small enough for consistency with theoretical models remains unknown.[14]

Similarly, recent theoretical work suggests reasons for weaker adjustment of exchange rates toward purchasing power parity when the economy is close to its long-run equilibrium. Uppal and Sercu (1996) have explored a simple model of international arbitrage costs in product markets that implies little or no adjustment of real exchange rates toward long-run levels when the economy is close to long-run equilibrium. Proportional arbitrage costs create a *no-arbitrage band* around a long-run equilibrium, in which the real exchange rate can vary without tendency to return to a mean.[15] Outside that band,

[14] The theoretical models discussed above use the same shocks to generate business cycles and changes in real exchange rates, so they predict not only correlations between the two but similar half-lives of real exchange rates and output ratios. More research is required to test this prediction of the models.

[15] In a simple version of this model, countries are autarkic within the no-arbitrage band and the real exchange rate is indeterminate within the limits of that band. Consider a simple static model with a single homogeneous good randomly endowed and consumed in each of two countries. Imagine that the countries are identical ex ante in every respect. Suppose there are "iceberg" costs associated with shipping a good from one country to the other—when one unit of a good is exported by either country, only $k < 1$ goods arrive in the other country. (This situation resembles the commodity points discussed by Heckscher (1916) in analogy to the gold points of the classical gold standard, or zones of inaction in models of irreversible investment, or s-S inventory models.) Consider the equilibrium of such a model with complete markets in which consumers trade in asset markets prior to knowing the levels of random endowments. The equilibrium involves a no-arbitrage band—if endowments are sufficiently similar, then people consume their endowments, while if endowments are sufficiently dissimilar, then people with high endowments ship some of their goods to people with low endowments. Because of the "iceberg" costs of shipping, consumers choose not to trade on asset markets and not to equate consumption

arbitrage opportunities lead the real exchange rate back toward the band. This arbitrage-cost framework provides a loose interpretation of the recent empirical work mentioned above.[16] Ohanian and Stockman (1997) have extended the model developed by Uppal and his coauthors to a dynamic context.[17] While their model is directed at a different issue (explaining commonly suggested connections between exchange rates and international portfolio adjustments), it also implies that factors generating international portfolio adjustments inside the no-arbitrage band could mask connections between real exchange rates and other variables. As a result, connections between the real exchange rate and other variables, such as the output ratio, may be stronger outside that band. More generally, the signal-to-noise ratio may be larger when shocks are larger and drive either the output ratio or real exchange rate farther from its long-run equilibrium; we exploit this idea empirically below.

A key issue in analyzing exchange-rate data involves the choice of whether and how to filter those data. The correlations in Table 1 would be meaningless if either q_{ab} or y_{ab} were nonstationary. Unfortunately, standard statistical tests are unable to distinguish between the two main alternative hypotheses about these data: that they are trend-stationary or that they contain unit roots. This inability to distinguish the form of the trend in these data is not unique to this article—it plagues almost all analyses of real exchange-rate data and, indeed, macroeconomic analysis more generally. The hypothesis of trend-stationarity in q_{ab} means that the probability distribution of q_{ab} is stationary after a deterministic time trend has been removed from q_{ab}. The alternative hypothesis of a unit root in q_{ab} means that q_{ab} has a random trend, in the sense that the probability distribution of *changes* in q_{ab} is stationary. The same applies to trends in y_{ab}. One can investigate these trends by testing for the presence of a unit root in a standard unit-root test, such as the augmented Dickey-Fuller test. The results of unit-root tests for q_{ab} or y_{ab} are available from the author; however, they share a common characteristic with many unit-root tests in macroeconomic data in that they yield ambiguous results.

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in the two countries. While a modified version of purchasing power parity holds outside the band, within the band, nominal and real exchange rates are indeterminate. With sticky prices or real costs of arbitrage outside the band, the real exchange rate can deviate from the band with only a slow tendency to return in the long run. It is this idea that forms the basis for the recent empirical studies of nonlinearities in exchange-rate behavior.

This simple model leaves many questions open. What are the arbitrage costs? How large are they? Evidence indicates that they are connected not only with distance but national borders—see Engel and Rogers (1996)—without providing reasons for this connection. These questions pose challenges for future research.

[16] The interpretation is loose for several reasons. One reason is that most recent empirical work uses linearly detrended (real or nominal) exchange-rate data. While changes in equilibrium relative prices may create such trends, the statistical models do not take into account the effects of this trend on the rate at which arbitrage would push the exchange rate back toward the (moving) band.

[17] See Uppal (1993); Uppal, Sercu, and Van Hulle (1995); and Uppal and Sercu (1996).

Unit-root tests have many well-known problems. One serious problem is that these tests have low power to reject unit roots (correctly, when the data in fact do *not* have unit roots) in short samples like those available for the current analysis, particularly when the true root is close to unity. For example, the power to reject a unit root is low in a short sample when a series follows a first-order autoregressive process, $y_t = \alpha y_{t-1} + u_t$, where $-1 < \alpha < 1$, but the root α is 0.95 or some other number close to 1. The power of these tests to reject unit roots correctly is also low when the data follow a more complicated (but stationary) time-series process, like the nonlinear processes studied in the papers mentioned in footnote 13. For example, Taylor and Peel (1997) show that nonlinear mean reversion can create a high probability of failing to reject unit roots when using standard methods, even when the data are actually stationary. For these reasons, this article follows most other research on real exchange rates by treating real exchange rates q as trend-stationary. For similar reasons, we also treat real-GDP ratios y as trend-stationary. This assumption makes results in this article more easily comparable with the bulk of other empirical work in the area.[18]

We begin with an examination of whether the detrended series, *DTq* and *DTy*, is more strongly related when one of the series is large (in absolute value) relative to its mean. Table 2 shows conditional correlations between detrended GDP ratios (*DTy*) and detrended real exchange rates (*DTq*) when the absolute value of the detrended real exchange rate is large. The first column of statistics shows unconditional correlations; the second column shows the correlations that are conditional on the absolute value of $DTq > 0.1$ (which means that the detrended real exchange rate is at least 10 percent above or below its mean). The interpretation of this table requires an economic model. One might think about an arbitrage model with a no-arbitrage band of unknown size and interpret the table as capturing situations in which the exchange rate is outside that arbitrage band. Alternatively, one might think that many factors other than business-cycle conditions affect the relationship between exchange rates and output ratios in normal times and that when the exchange rate is close to its mean, this "noise" makes it difficult to detect a consistent relationship. Under this interpretation, larger deviations of exchange rates from their means may indicate times when the "signal-to-noise" ratio is larger, allowing economists potentially to observe the relationships predicted by the theories outlined earlier.

[18] The usual assumption that the real exchange rate is trend-stationary, adopted here, implies a *failure* of long-run absolute purchasing power parity (though not relative purchasing power parity). The underlying assumption is that something—like differences in productivity growth causing differences in the trend relative price of nontraded goods, which are part of the bundles of goods included in the real exchange rate measure—cause the equilibrium real exchange rate to show a trend. The data clearly support the presence of *some* trend, whether stochastic or (as here) deterministic and linear.

Table 2 Correlations between Detrended Exchange Rates and GDP Ratios Conditional on Size of Exchange Rates

Country Pair	Unconditional	ABS(*DTq*) > 0.1	ABS(*DTq*) > 0.15	ABS(*DTq*) > 0.2
U.K., Japan	0.66	0.78	0.79	0.79
France, Japan	−0.21	−0.31	−0.01	−0.02
Italy, Japan	0.15	0.14	0.24	0.34
Switzerland, Japan	0.08	0.17	0.20	NA
Australia, Japan	0.18	0.29	NA	NA
Netherlands, Japan	−0.32	−0.45	NA	NA
Spain, Japan	−0.03	0.05	0.25	NA
Canada, Japan	0.41	0.50	0.46	NA
U.K., U.S.	−0.12	−0.27	−0.42	NA
France, U.S.	−0.21	−0.69	NA	NA
Italy, U.S.	0.01	0.01	−0.15	NA
Switzerland, U.S.	0.16	0.27	0.38	0.63
Australia, U.S.	−0.23	−0.59	0.21	0.26
Netherlands, U.S.	−0.47	−0.64	−0.63	NA
Spain, U.S.	−0.50	−0.57	NA	NA
Japan, U.S.	0.46	0.62	0.68	0.69

NA = Not available due to insufficient number of observations.

Table 2 examines the connection between output ratios and real exchange rates when the latter are far from their detrended means, measured as when the absolute value of the detrended log real exchange rate—ABS(*DTq*)—exceeds 0.1, 0.15, or 0.2. The results show, at best, a very weak connection between output ratios and exchange rates even when exchange rates are far from their means. Half (eight of 16) of the unconditional simple correlations are positive; only nine of 16 are positive when the absolute value of the detrended exchange rate exceeds its mean by 10 percent or more.

Table 3 is analogous to Table 2 in that it shows conditional correlations between detrended GDP ratios (*DTy*) and detrended real exchange rates (*DTq*). While Table 2 conditions on a large real exchange rate, Table 3 conditions on a large absolute value of the detrended output ratio. Again, one might use the arbitrage model to interpret this table as capturing situations in which the economy is outside the arbitrage band. Alternatively, one might think of large output ratios as indicating times when the signal-to-noise ratio is large enough that we could find evidence of the comovements predicted by the theories outlined above.

Like the results of Table 2, those in Table 3 fail to show any strong connection between output ratios and exchange rates even when output ratios are far from their means. The first column of statistics shows unconditional correlations between real exchange rates and output ratios; the second column shows the

Table 3 Correlations between Detrended Exchange Rates and GDP Ratios Conditional on Size of GDP Ratios

Country Pair	Unconditional	ABS(*DTy*) > 0.01	ABS(*DTy*) > 0.02	ABS(*DTy*) > 0.03
U.K., Japan	0.63	0.67	0.73	0.78
France, Japan	−0.19	−0.22	−0.32	−0.29
Italy, Japan	0.23	0.28	0.23	0.22
Switzerland, Japan	0.10	0.08	0.18	0.36
Australia, Japan	0.18	0.25	0.34	0.33
Netherlands, Japan	−0.32	−0.34	−0.32	−0.38
Spain, Japan	−0.03	−0.03	−0.06	−0.13
Canada, Japan	0.54	0.59	0.75	0.81
U.K., U.S.	−0.12	−0.14	−0.20	−0.10
France, U.S.	−0.21	−0.23	−0.22	−0.25
Italy, U.S.	0.03	0.02	0.10	0.25
Switzerland, U.S.	0.15	0.15	0.18	0.40
Australia, U.S.	−0.23	−0.28	−0.27	−0.11
Netherlands, U.S.	−0.47	−0.52	−0.53	−0.47
Spain, U.S.	−0.50	−0.55	−0.57	−0.64
Japan, U.S.	0.46	0.63	0.66	0.66

correlations conditional on the absolute value of $DTy > 0.01$ (which means that the detrended output ratio is at least 1 percent above or below its mean). Other columns show the results for larger values of output ratios. Evidently, the correlation is not much different when the real exchange rate is far from its mean (as in the last three columns of Table 2) or when the output ratio is far from its mean (as in the last three columns of Table 3) than when both are close to their means.

Tables 2 and 3 address the issue of large versus small values of detrended real exchange rates and output ratios but not issues of transitory versus more persistent changes in these variables. Business cycles refer to changes in real GDP that are sustained over at least several quarters. One might expect a stronger relationship between exchange rates and real GDP over business cycles and longer periods than over short periods, which may see many unrelated, transitory changes in output ratios and exchange rates.

We now turn to the connection between real exchange rates and output ratios when changes in either are sustained for several quarters. Table 4 shows that the results change substantially when we condition in a different way to capture business cycles. Although the table focuses on Japan as the base country, similar results appear when the United States is the base country. Column 1 shows the percentage of positive observations of a country's detrended real exchange rate over the entire sample. The numbers are all close to one-half. Column 2 shows the percentage of positive observations of a country's

Table 4 Percentage of *Positive* Detrended Real Exchange Rates When Detrended GDP Ratios are *Positive*

	1	2	3	4	5	6
		Percent of Positive Observations				**Marginal**
Country Pair	**in whole sample**	**if $DTy > 0$**	**if $DTy > 0$ for two quarters**	**if $DTy > 0$ for four quarters**	**if $DTy > 0$ for six quarters**	**probability level for column 5**
U.K., Japan	52	82	87	91	89	10^{-6}
Canada, Japan	46	66	73	74	75	0.002
Switzerland, Japan	53	68	75	73	88	0.002
U.S., Japan	54	70	77	81	72	0.02
France, Japan	54	51	54	56	64	0.18
Netherlands, Japan	52	52	50	50	65	0.26
Italy, Japan	52	56	58	55	58	0.54
Spain, Japan	52	49	50	51	45	0.73
Australia, Japan	45	47	48	38	52	1

detrended real exchange rate conditional upon its detrended GDP ratio being positive in the same quarter. In six of nine cases, the percentage of positive observations of the detrended exchange rate is larger than in the entire sample (column 1). Columns 3 through 5 show the same information conditional upon detrended GDP ratios being positive for the next two, four, or six consecutive quarters. The percentage of positive detrended exchange rates is generally larger when we condition on positive GDP ratios. This result occurs in eight out of nine cases in column 5, and in most cases the percentage is quite high. Column 6 shows the marginal probability level for rejecting the null hypothesis that the numbers in column 5 arise purely by chance (such as when one draws them randomly from a binomial distribution). This "sign test" (treating positive and negative observations as binomial draws) assumes that the underlying distribution is symmetric, which appears to be roughly true in these data. (The fact that the numbers in the first column are close to one-half is consistent with this assumption). In four of the nine cases (the United Kingdom, Canada, Switzerland, and the United States), we can strongly reject the null hypothesis that the connection between detrended real exchange rates and detrended GDP ratios arises purely by chance. Even in the five cases in which we cannot reject that null hypothesis, more than half of the observations are positive in four of the five cases (France, the Netherlands, Italy, and Australia). For example, column 5 shows that almost two-thirds of the observations are positive for both France and the Netherlands.

One can achieve greater statistical power by pooling the data; however, the probability distribution is exceedingly complicated when one allows for dependence across country pairs. Overall, nearly two-thirds of the observations

Table 5 Percentage of *Positive* Detrended GDP Ratios When Detrended Real Exchange Rates are *Positive*

	1	2	3	4	5	6
		Percent of Positive Observations				
Country Pair	in whole sample	if $DTq > 0$	if $DTq > 0$ for two quarters	if $DTq > 0$ for four quarters	if $DTq > 0$ for six quarters	Marginal probability level for column 5
U.K., Japan	42	70	72	77	77	0.01
Canada, Japan	38	60	63	71	75	0.01
U.S., Japan	45	63	72	78	72	0.04
Australia, Japan	53	58	57	59	65	0.11
Switzerland, Japan	59	65	67	63	68	0.14
France, Japan	52	48	51	53	62	0.38
Spain, Japan	48	41	45	48	54	0.84
Netherlands, Japan	52	43	42	43	42	0.65
Italy, Japan	41	50	53	52	47	1

on the detrended real exchange rate in column 5 of Table 4 are negative (with 264 observations in that column, the detrended exchange rate is negative in 183 instances and positive in 81 instances). The probability that this occurs purely by chance would be only three hundred-millionths of 1 percent if data on detrended GDP ratios and exchange rates in each row of the table were independent. Of course, the fact that Japan is involved in each comparison means that the data are probably dependent. However, even with dependence across observations, the results in this table show strong evidence that when a country's detrended GDP rises for six straight quarters relative to Japan, its currency tends to take a low value on foreign exchange markets (q is high).

Table 5 shows analogous calculations that are conditional upon sustained depreciation of real exchange rates. Column 1 of Table 5 shows the percentage of positive observations of a country's detrended output ratio over the entire sample. Column 2 shows the percentage of positive observations of a country's detrended output ratio conditional upon its detrended real exchange rate being positive in the same quarter. Except in the Netherlands (and Spain for durations shorter than six quarters), exchange rates show real depreciation significantly more often when the GDP ratio is high for several quarters (than in the overall sample). Unfortunately, the number of observations available for calculations in column 6 is sufficiently low that we can strongly reject the null hypothesis that this result arises purely by chance for only three of the nine cases in column 5—for the United Kingdom, Spain, and the United States.

Tables 4 and 5 examine groupings of observations in these data that are conditional upon whether one of the variables exceeds its mean for some duration. Table 6 extends this evidence by testing the null hypothesis that

Table 6 Test Results: Means of Detrended Exchange Rates Conditional on Signs of Detrended GDP Ratios

Country Pair	1 **Mean detrended (log) exchange rate if detrended GDP ratio exceeds its median**	2 **Mean detrended (log) exchange rate if detrended GDP ratio is less than its median**	3 **t-statistic for null hypothesis that the means in columns 1 and 2 are equal**
U.K., Japan	0.08	−0.08	−11.0
Canada, Japan	0.07	−0.07	−9.0
U.S., Japan	0.05	−0.05	−6.4
Italy, Japan	0.01	−0.05	−4.3
Australia, U.S.	0.03	−0.02	−3.0
Switzerland, Japan	0.01	−0.00	−0.6
Spain, Japan	0.00	0.00	1.1
France, Japan	−0.01	0.01	2.3
Netherlands, Japan	−0.01	0.03	4.3

the mean detrended exchange rate does not depend on whether the detrended GDP ratio is above or below its median value. The large absolute values of the t-statistics in column 3 of Table 6 indicate rejection of that null hypothesis. In seven of nine cases, we can reject the hypothesis that the means of the real exchange rates do not depend on the GDP ratio. In five of those seven cases the direction of the difference in means is the direction predicted by standard models. The exceptions are France and the Netherlands. In most cases, the evidence in this table, as in Tables 4 and 5, clearly indicates that high GDP ratios and depreciated real exchange rates tend to occur together in the data.

Because the results of Tables 4 and 5 indicate that the connection between real exchange rates and GDP ratios is strongest when one of the series shows sustained movement away from its mean, Table 7 adds duration to the test shown in Table 6. Specifically, it repeats the test in Table 6 with the condition that the detrended GDP ratio is above or below its median value for six straight quarters. In every case we can reject the hypothesis that the means do not depend on the GDP ratio; in six of the nine cases, the connection is in the direction predicted by standard models. Spain now joins France and the Netherlands as exceptions. Table 7 provides even stronger evidence that high GDP ratios and depreciated real exchange rates tend to occur together.

Together, Tables 4 through 7 provide the strongest evidence currently available that changes in real exchange rates are connected to changes in real-GDP ratios over periods of several quarters, as predicted by nearly all existing models of exchange rates.

Table 7 Test Results: Means of Detrended Exchange Rates Conditional on Signs and Duration of Detrended GDP Ratios

Country Pair	1 **Mean detrended (log) exchange rate if detrended GDP ratio exceeds its median for six straight quarters**	2 **Mean detrended (log) exchange rate if detrended GDP ratio is less than its median for six straight quarters**	3 **t-statistic for null hypothesis that the means in columns 1 and 2 are equal**
U.K., Japan	0.11	−0.13	−15.9
Canada, Japan	0.10	−0.10	−12.3
U.S., Japan	0.06	−0.05	−6.9
Italy, Japan	0.02	−0.11	−9.4
Australia, U.S.	0.04	−0.07	−6.8
Switzerland, Japan	0.06	−0.02	−8.3
Spain, Japan	−0.03	0.02	2.9
France, Japan	0.01	0.03	2.3
Netherlands, Japan	−0.01	0.04	5.1

3. CONCLUSIONS

The inability of economists to find strong statistical relationships between exchange rates and underlying economic conditions has been a huge puzzle in international economics. In particular, standard models of both the sticky-price and flexible-price varieties predict that real depreciations of a country's currency tend to occur along with increases in its output relative to foreign output. The findings reported here are probably the strongest evidence yet that this relationship appears in the data. The same findings show that the relationship is nonlinear and conditional. These empirical results raise a set of new questions for future research, particularly regarding related nonlinear and conditional connections between exchange rates and other variables. It appears that exchange rates, after all, do not have lives of their own.

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