Title
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A BETTER MEASURE OF RELATIVE VOLATILITY*

I would like to suggest a better way to measure the relative volatility of exchange rates and appropriate ratios of price levels or price indexes. The usual way to measure such volatility is to compare the variability of monthly changes in exchange rates to the variability of monthly changes in relative price indexes.[1] A closely related method is to measure how much of the variance for monthly changes in real exchange rates is explained by monthly changes in nominal exchange rates.[2] Both approaches implicitly use purchasing power parity as the benchmark for an appropriate level of volatility. Both approaches support the widely held belief that flexible exchange rates are too volatile.[3] However, because exchange rates are auction prices and price indexes are not, comparing the variability of the two series exaggerates the relative volatility of flexible exchange rates.[4]

A related problem exists in the rapidly growing literature on border effects.[5] That literature involves two variances. One is the variance for changes in say the price of shoes in New York relative to their price in Los Angeles. The second is the variance for changes in the price of shoes in New York relative to their price in London where the sterling price is converted into dollars using an appropriate exchange rate. When commodity prices are from non-auction markets and exchange rates are from auction markets, the second variance will be larger than the first even if commodity arbitrage between auction markets is as effective between New York and London as between New York and Los Angeles. As a result, such comparisons can exaggerate border effects.[6]

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1 See for example Isard (1995) and Bleaney (1992). For a different approach see Bartolini and Bodnar (1996)

2 "...variability of *real* exchange rates has primarily reflected variability of nominal exchange rates." Frenkel and Goldstein (1988, 188). Also see De Grauwe and Verfaille (1988).

3 Not everyone believes that the volatility of exchange rates is excessive. See for example Bergstrand (1983), Frenkel and Goldstein (1988), Bui and Pippenger (1990) and Bartolini and Bodnar (1996).

4 In a similar way, sticky dividends compound the small sample bias in tests of variance bounds. See Gilles and LeRoy (1991).

5 For some of the recent literature on border effects, see Engle and Rogers (2001) and Parsley and Wei (2001).

6 The typical test for border effects regresses these variances against a dummy for whether or not there is a border, the variance for the appropriate exchange rate, a distance measure and other explanatory variables.

Using variance to measure variability, the first section shows how conventional measures of relative volatility exaggerate the relative volatility of flexible exchange rates. That section also shows how the frequency domain can provide a less biased measure of relative volatility and can help identify the source of any extra volatility in exchange rates.[7] After a description of the data, the following section compares the results of using variance and spectra to measure relative volatility. Using both the United States and Great Britain as base countries, spectral estimates substantially reduce, but do not entirely eliminate, the evidence that flexible exchange rates are more volatile than is consistent with purchasing power parity. However spectral estimates raise questions about whether the additional volatility in exchange rates should be called 'excessive'.

I. Measuring Relative Volatility

It is widely recognized that price indexes are sticky while exchange rates are not. Frenkel and Goldstein (1988, p.189) describe the difference between price indexes and exchange rates as follows: "...aggregate price indices are sticky, backward-looking variables that, typically, largely reflect past contracts, whereas nominal exchange rates are jumpy, auction prices that anticipate future events."[8] However no one has fully appreciated how this difference affects conventional measures of relative volatility.

Two factors combine to bias upwards measures of relative volatility. First, the two variances are not comparable in the sense that their spectral shapes are very different. Second, purchasing power parity is a long-run theory.

If standard price indexes used auction prices, then we would expect the spectrum for changes in relative price indexes to be fairly flat.[9] In that case, the two variances would be comparable in the

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[7] Variance is the power in a stationary time series. The spectrum describes how that power is distributed across frequency. For an excellent discussion of spectral analysis see Jenkins and Watts (1969).

[8] One can say the same thing about dividends and stock prices.

[9] When using auction prices, the variance for the change in the exchange rate implied by the law of one price tends to be larger than the variance for the change in the actual exchange rate and both changes are approximately white noise. See Bui and Pippenger (1990).

sense that the distribution of power across frequency would be similar. However sticky prices cause changes in ratios of price indexes to have spectra that are low at high frequency and rise rapidly as frequency approaches zero.

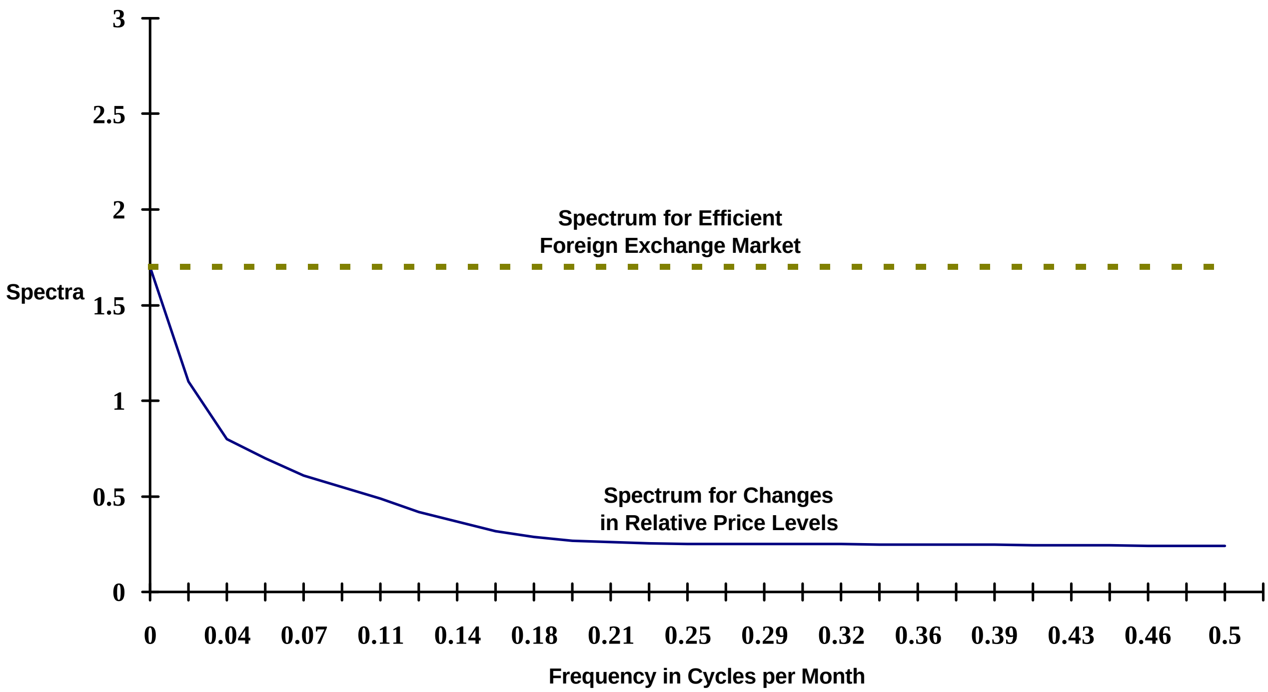
Because purchasing power parity is a long-run theory, only part of the power in changes in relative price indexes is relevant. That power is the long-run power, *i.e.*, the power at low frequencies. Since the power at the lowest frequencies is much larger than at high frequencies, the variance for changes in relative price indexes seriously underestimates the volatility of relative price indexes that is consistent with purchasing power parity. Because of that underestimate, comparing variances seriously overstates the volatility of exchange rates relative to the volatility consistent with purchasing power parity. Since the spectrum decomposes variance by frequency, using the frequency domain can solve that problem.

Figure 1 below illustrates the difference between the two spectra. To show how that difference generates a bias toward excessive volatility, Figure 1 assumes that the market for foreign exchange is efficient and that purchasing power parity holds in the long run. By construction, the volatility of exchange rates in Figure 1 is not excessive.

The solid line in Figure 1 shows a typical spectrum for changes in relative price indexes. The area under that line represents the variance in the series. The dashed line shows the spectrum for changes in exchange rates where the market is efficient and changes are white noise. The area under the dashed line represents the variance for changes in exchange rates.

In Figure 1, the volatility of exchange rates is consistent with purchasing power parity. At zero frequency, the power in the two series is the same. Notice that, although the short-run power in exchange rates is much larger than the short-run power in relative price indexes, the short-run volatility of exchange rates is consistent with purchasing power parity. The fact that the spectrum at high frequency is much larger for exchange rates than for ratios of price indexes is irrelevant. With an efficient market for exchange rates, it is the long-run power in ratios of price indexes that determines both the long-run and short-run power in exchange rates.[10]

FIGURE 1
Spectra for an Efficient Foreign Exchange Market where Purchasing Power Parity Holds



By construction, there is no excess volatility in Figure 1. However relative variances imply that exchange rates are more volatile than is consistent with purchasing power parity. Since the area under the spectrum represents the variance in a series, the variance for changes in exchange rates is obviously larger than the variance for changes in relative price indexes. Using relative spectral estimates at 0.0 would provide an unbiased estimate of relative volatility.

The frequency domain not only provides a better way to measure relative volatility, it also provides some insight into the sources of any additional volatility for changes in exchange rates. Figure 2 below illustrates how the frequency domain can provide that insight. The spectrum for changes in relative price indexes is the same as in Figure 1. However now there are two new spectra for changes in exchange rates. The heavy dashed line describes a situation where the foreign

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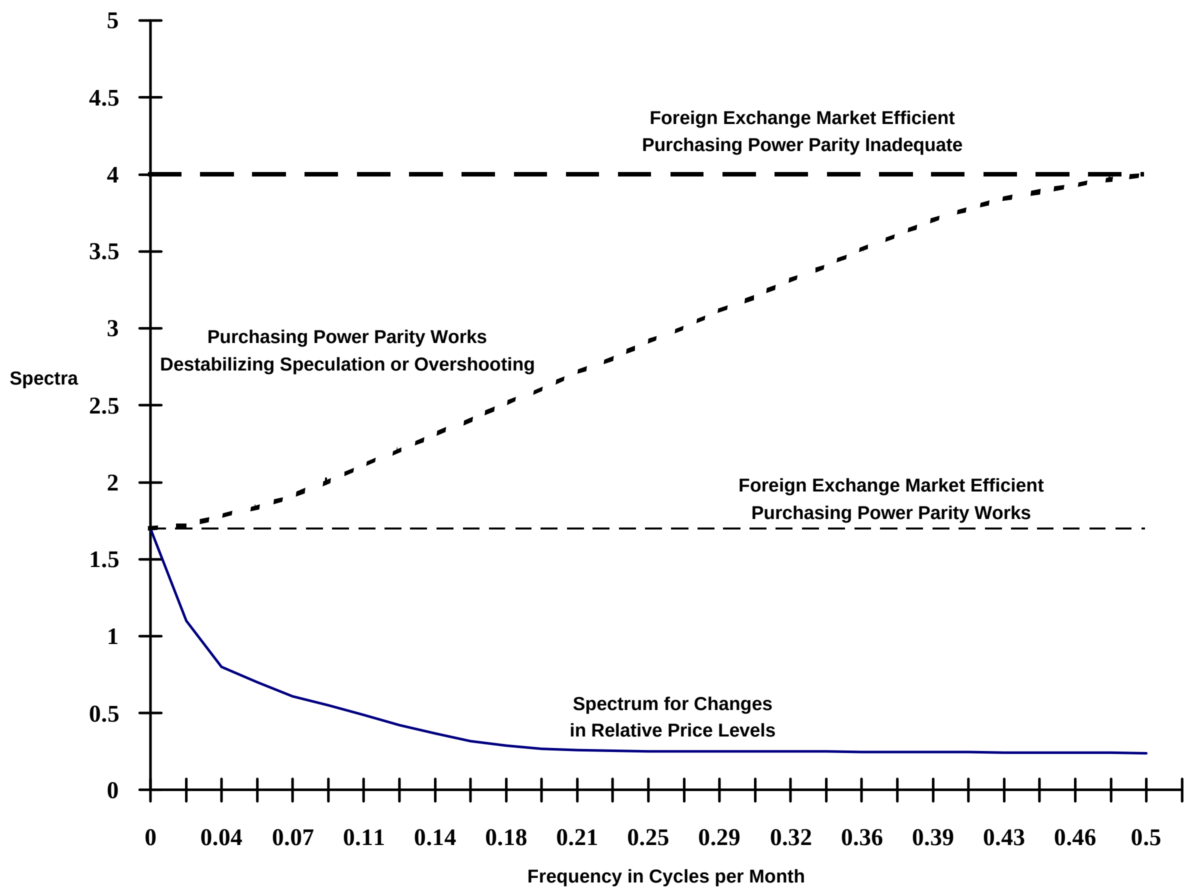
10 If other fundamentals are long-run determinants of exchange rates, a similar argument holds for them.

exchange market is efficient, but exchange rates are more volatile than is consistent with purchasing power parity. The dotted line describes a situation where exchange rates are consistent with purchasing power parity in the long run, but some destabilizing influence increases the short-run power in exchange rates. The shape of the dotted line is what we would expect with destabilizing speculation such as bandwagons or nominal overshooting as in Dornbusch (1976).[11] In both situations, exchange rates are more volatile than is consistent with purchasing power parity. But the interpretation of that fact is different in the two cases.

FIGURE 2
Sources of Excess Volatility



11 For a formal derivation of the spectral implications of the Dornbusch model see Bui and Pippenger (1990).

With the dashed line, even in the long run, there is more power in exchange rates than is consistent with purchasing power parity. However, because the foreign exchange market is efficient, it is difficult to claim that the volatility of exchange rates is excessive. A reasonable interpretation of the dashed spectrum is that purchasing power parity is an important determinant of exchange rates, but that other economic fundamentals also affect exchange rates.

The shape of the dotted spectrum for changes in exchange rates is probably what most people have in mind when they refer to 'excessive' volatility. In that case, something is causing the short-run variability of exchange rates to be larger than it would be in an efficient market. I believe that almost everyone would agree that the dotted spectrum qualifies as 'excessive' volatility.

Of course these two possibilities are not mutually exclusive. The long-run variability of exchange rates could be larger than is consistent with purchasing power parity because other fundamentals affect exchange rates while overshooting or bandwagons further increase short-run variability. Although that is a possibility, the evidence from the frequency domain suggests that there is no overshooting or bandwagons.

II. Data

Exchange rates and CPIs are from the CD ROM for *International Financial Statistics*, September 2000, produced by the International Monetary Fund. Exchange rates are end of period. To allow for a transition from generally pegged exchange rates to more flexible exchange rates, the data start in 1975. The data end in 1998 with the initial stages in the adoption of the euro. Observations cover 21 developed countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Great Britain, Ireland, Italy, Japan, Luxembourg, The Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland and the United States. All series are monthly, except for Australia, Ireland and New Zealand where monthly CPIs are not available. For those countries the series are quarterly. Changes in exchange rates and relative CPIs are differences in logs times 100.

III. Comparison

$\sigma^2_{\Delta s}$ and $\sigma^2_{\Delta p}$ are the variances for changes in exchange rates and relative CPIs respectively. $\Gamma_{\Delta s}(0.0)$ and $\Gamma_{\Delta p}(0.0)$ are the spectral estimates at zero frequency (infinite cycle) for changes in exchange rates and relative CPIs respectively. $\Gamma_{\Delta s}(0.5)$ is the spectral estimate for changes in exchange rates at the highest frequency (a two month cycle for monthly data and a six month cycle for quarterly data). Spectral estimates use a modified Bio Med program. That program and the data are available on request.

TABLE 1
Different Measures of Relative Volatility: United States as Base Country

Country	$\sigma^2_{\Delta S}/\sigma^2_{\Delta P}$	$\Gamma_{\Delta S}(0.0)/\Gamma_{\Delta P}(0.0)$	$\Gamma_{\Delta S}(0.5)/\Gamma_{\Delta P}(0.0)$
Australia*	18.41	4.81	3.47
Austria	47.82	19.13	9.68
Belgium	77.51	19.39	8.52
Canada	14.85	5.89	5.04
Denmark	29.50	29.07	11.56
Finland	46.16	11.24	4.84
France	105.05	19.75	7.39
Germany	79.86	19.68	10.31
Ireland*	16.44	6.02	1.44
Italy	41.42	8.54	2.00
Japan	34.82	23.31	14.66
Luxembourg	81.48	16.47	7.24
Netherlands	54.08	19.04	12.19
New Zealand*	15.48	4.52	1.24
Norway	35.53	7.08	3.59
Portugal	8.07	3.62	0.77
Spain	25.07	7.66	2.92
Sweden	29.28	16.67	4.69
Switzerland	53.47	14.38	5.79
Great Britain	26.38	9.41	2.82
Average	42.03	13.28	6.01

*Quarterly Data. Spectral estimates use 28 lags for monthly data and 10 lags for quarterly.

In Table 1 the United States is the base country. In Table 2 Great Britain is the base country. Both tables report individual and average estimates for $\sigma^2_{\Delta s}/\sigma^2_{\Delta p}$, $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$ and $\Gamma_{\Delta s}(0.5)/\Gamma_{\Delta p}(0.0)$.

A. *United States as Base Country*

In Table 1 above, the first column after a country's name shows the variance for changes in exchange rates divided by the variance for changes in relative CPIs. Portugal has the lowest ratio, 8.07. France has the highest ratio, 105.05. For all 20 countries, the average is 42.03. An average relative volatility of 42 appears large. Taken at face value, that number supports the idea that the volatility of exchange rates is excessive relative to the benchmark of purchasing power parity. However that number is biased upward and variances cannot distinguish between the two sources for additional volatility illustrated in Figure 2. The next two columns in Table 1 use the frequency domain to help resolve these issues.

The column labeled $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$ compares the long-run power in exchange rates to the long-run power in relative price indexes. Using $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$ rather than $\sigma^2_{\Delta s}/\sigma^2_{\Delta P}$ reduces relative volatility for every country. For some countries, relative volatility falls dramatically. France falls from 105.05 to 19.75. For some countries the decline is small. Sweden only falls from 29.28 to 16.67. Denmark barely falls at all.[12] On average, using $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$ reduces relative volatility from 42.03 to 13.28. A 68 percent reduction.

Figure 2 suggests two possible explanations for this reduction in excess volatility.[13] One possibility is that $\Gamma_{\Delta p}(0.0)$ eliminates the bias from sticky prices. The other possibility is that $\Gamma_{\Delta s}(0.0)$ filters out the effects of overshooting or destabilizing speculation. A simple way to see

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[12] The Danish decline is so small because the spectrum for changes in relative price indexes is relatively flat. With Great Britain as the base country, the spectral shape is more typical. However, in both cases spectral estimates for relative price indexes rise sharply at the two highest frequencies and spectral estimates are larger at 0.5 than at 0.0. This pattern suggests that there may be some errors in the CPI for Denmark.

[13] Bubbles are another possible source for 'excessive' volatility. However it is not clear how bubbles would affect the distribution of power across frequencies. For a discussion of bubbles in the context of variance-bounds tests, see West (1988).

which is responsible for the reduction is to compare $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$ to $\Gamma_{\Delta s}(0.5)/\Gamma_{\Delta p}(0.0)$. If $\Gamma_{\Delta s}(0.0)$ is filtering out short-run volatility from overshooting or destabilizing speculation, $\Gamma_{\Delta s}(0.5)/\Gamma_{\Delta p}(0.0)$ should be larger than $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$. Excess volatility should be larger in the short run than in the long run.

The column farthest to the right in Table 1 shows the estimates for $\Gamma_{\Delta s}(5.0)/\Gamma_{\Delta p}(0.0)$. In every case $\Gamma_{\Delta s}(0.5)/\Gamma_{\Delta p}(0.0)$ is smaller than $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$. There is no evidence of overshooting or destabilizing speculation. Instead something seems to be reducing the short-run power in exchange rates. A likely candidate for any reduction is leaning against the wind by central banks.[14] Whatever the source for any reduction in power, all of the decline in relative volatility from using $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$ rather than $\sigma^2_{\Delta s}/\sigma^2_{\Delta P}$ appears to be due to reducing the bias from sticky prices.

B. *Great Britain as Base Country*

Most of the countries in Table 1 are not viable candidates as an alternative base country. For the purposes of this work, Canada is almost a proxy for the United States. Exchange rates between members of the European Exchange Rate Mechanism were not flexible. Australia and New Zealand are relatively small. Although they are falling, Japan has had a wide range of barriers in both trade and capital flows. Great Britain flirted with the ERM in the early 1990s, but it never joined and has had essentially flexible exchange rates with all countries over most of the interval used here.[15] For that reason, I use Great Britain as the second base country.

Table 2 below shows the same information as Table 1, but with Great Britain as the base country. Except for Australia, Canada and of course the United States, relative volatility using variances is smaller with Britain as the home country. The same is true when using relative spectral estimates at zero frequency to measure relative power in the long run. Using Great Britain rather than the United States as the base country causes the average ratio of variances to drop from 42.03 to 12.37. A 71

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[14] See Pippenger and Phillips (1973), Phillips and Pippenger (1993) and Pippenger (2001) for evidence that leaning against the wind reduces the short-run volatility of exchange rates.

[15] From 1975 to mid 1979, the exchange rate between Britain and Ireland was fixed.

percent reduction. $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$ drops from 13.28 to 5.58. A 50 percent reduction. Dropping the United States from Table 2 changes the averages only slightly. Whichever way you measure it, there is less relative volatility with Great Britain as the base country.

TABLE 2
Different Measures of Relative Volatility: Great Britain as Base Country

Country	$\sigma^2_{\Delta s}/\sigma^2_{\Delta P}$	$\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta P}(0.0)$	$\Gamma_{\Delta s}(0.5)/\Gamma_{\Delta P}(0.0)$
Australia*	20.34	7.01	5.54
Austria	11.79	3.77	2.64
Belgium	14.98	4.76	2.85
Canada	21.38	10.96	3.56
Denmark	12.38	6.72	4.36
Finland	13.79	10.59	6.38
France	19.00	4.51	3.35
Germany	15.66	3.16	2.32
Ireland*	6.71	1.48	1.06
Italy	13.90	2.44	2.39
Japan	25.43	17.70	7.72
Luxembourg	15.26	4.34	2.65
Netherlands	15.26	5.11	3.87
New Zealand*	13.52	3.17	2.78
Norway	9.49	2.43	2.86
Portugal	4.85	2.10	1.12
Spain	11.09	3.30	3.74
Sweden	10.85	4.06	3.65
Switzerland	15.42	3.20	2.76
United States	26.38	9.41	2.82
Average	12.37	5.58	3.42
Average without U.S.	11.64	5.39	3.45

*Quarterly Data. Spectral estimates use 28 lags with monthly data and 10 lags with quarterly.

As in Table 1, using $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$ rather than $\sigma^2_{\Delta s}/\sigma^2_{\Delta P}$ substantially reduces relative volatility. In Table 2, relative volatility falls by about 55 percent.

There is no sign of destabilizing speculation or overshooting in Table 2. For most countries, $\Gamma_{\Delta s}(0.5)/\Gamma_{\Delta p}(0.0)$ is smaller than $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$. Using averages, $\Gamma_{\Delta s}(0.5)/\Gamma_{\Delta p}(0.0)$ is smaller, not larger, than $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$. However the reduction in short-run power for changes in exchange rates is smaller using Great Britain as the base country, only 36 percent rather than 55 percent. That difference is consistent with central banks as the source of the stabilizing influence because most intervention is *vis a vis* the U.S. dollar. Whatever the source of any reduction in the short-run power for changes in exchange rates, the reduction in relative volatility from using $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$ rather than $\sigma^2_{\Delta s}/\sigma^2_{\Delta P}$ again appears to be due to reducing the bias from sticky prices, not from filtering out the effects of overshooting or destabilizing speculation.

The evidence for 'excessive' volatility is even weaker in Table 2 than in Table 1. On average, the long-run volatility of exchange rates is only 5.58 times larger than is consistent with purchasing power parity. On average, the short-run volatility of exchange rates is only 3.42 times larger than is consistent with purchasing power parity. However even these numbers are probably biased upwards.

C. *Short Sample Bias*

To obtain useful degrees of freedom, raw spectral estimates are 'smoothed' or averaged. In the program used here, the smoothed estimate at zero frequency is a weighted average of the raw estimate at zero frequency and the raw estimate at the next lowest frequency. The weights are 0.54 for the estimate at 0.0 (the infinite cycle) and 0.46 for the estimate at 0.018 (a 55 month cycle with monthly data).

With relatively flat spectra such as those for changes in exchange rates, smoothing does not seriously distort the power at zero frequency even with a short sample. However, when spectra rise sharply as frequency approaches zero, smoothing can seriously bias downward estimates at zero frequency.

FIGURE 3
Average Spectral Density Estimates for Monthly Data: United States as Base Country

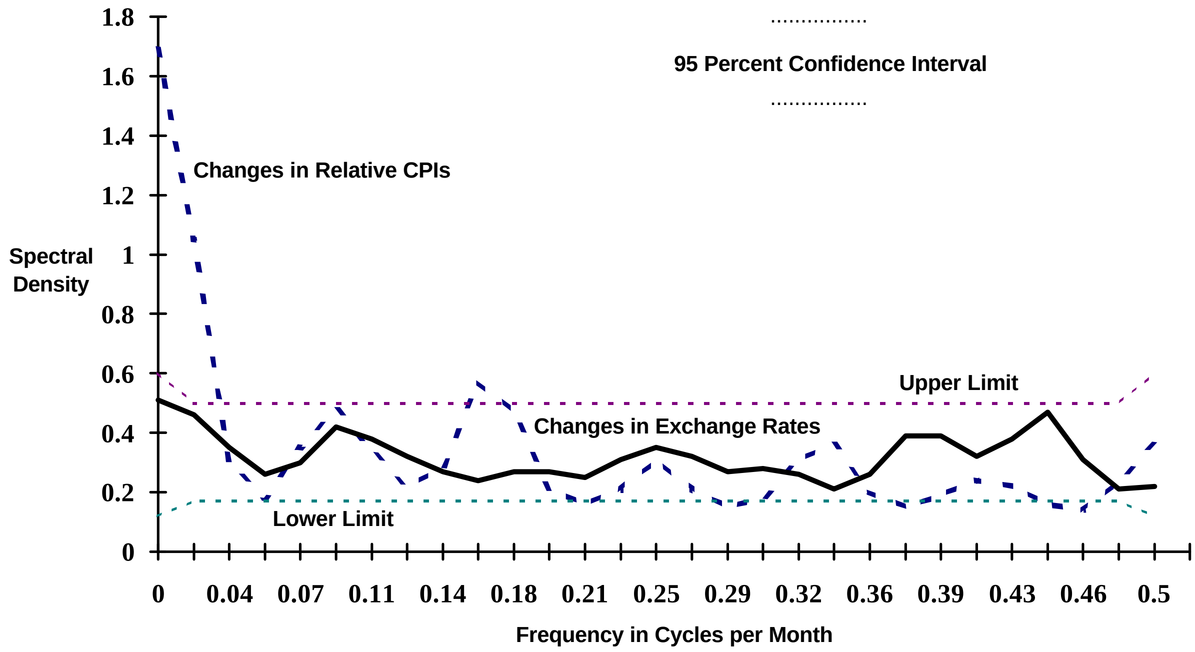

FIGURE 4
Average Spectral Density Estimates for Monthly Data: Great Britain as Base Country

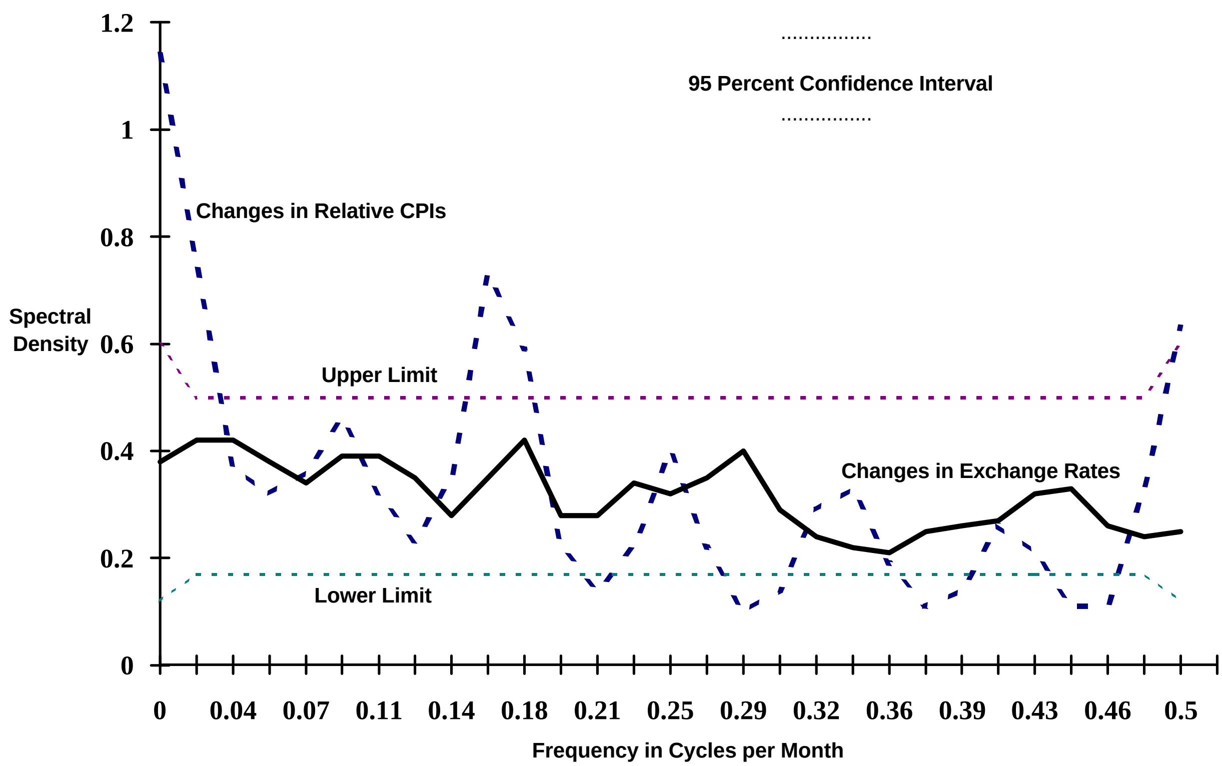

Figure 3 above shows the average of the spectral densities for countries in Table 1 with monthly data. Figure 4 above shows the average of the spectral densities for countries in Table 2 with monthly data. All estimates are smoothed. Spectral density is the normalized spectrum. That is, spectral density is the spectrum divided by the variance. Spectral density is to the spectrum as autocorrelation is to autocovariance. Using averages of spectral densities allows us to compare the typical shape of the spectra for changes in exchange rates to the typical shape for changes in relative price indexes.

Both figures contain a 95 percent confidence interval for white noise. Because each series includes the United States or Great Britain, spectral estimates across pairs of countries are not independent. The possibility that common shocks can affect several or all countries further reduces independence. As a result, confidence intervals based on independence would be too narrow. Since there is no obvious way to determine the degree of interdependence at any given frequency, I take a conservative approach. I use a 95 percent confidence interval for a single series.

In Figure 3, the typical spectral density for changes in exchange rates rises slightly as frequency approaches zero. In Figure 4, the typical spectral density for changes in exchange rates falls slightly as frequency approaches zero. In neither figure does the estimate for changes in exchange rates at 0.0, or any other frequency, lie outside the confidence band for white noise.

However, in both figures several spectral density estimates for changes in relative price indexes lie outside that confidence band. Estimates below 0.054 (an 18.5 month cycle) rise sharply as frequency declines. In both figures, the estimate for changes in relative price indexes at a frequency of 0.0 lies well above the confidence interval.[16] Both estimates are significantly different from white noise at the 1 percent level.

One way to deal with this problem is to use raw spectral estimates at zero frequency rather than smoothed estimates. That alternative reduces degrees of freedom, but it also reduces the potential for bias. Using raw estimates further reduces the evidence for excess volatility.

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[16] Particularly in Figure 4, there also is a significant peak at about 6 months,

Table 3
Smooth versus Raw Averages at Zero Frequency

Country	Smoothed $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$	Raw $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$	Smoothed $\Gamma_{\Delta s}(0.5)/\Gamma_{\Delta p}(0.0)$	Raw $\Gamma_{\Delta s}(0.5)/\Gamma_{\Delta p}(0.0)$
United States	13.28	7.81	6.01	3.47
Great Britain	5.58	2.26	3.42	1.82

Table 3 above shows the averaged smoothed and raw estimates at zero frequency. Using the United States as base country, raw estimates reduce $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$ by 41 percent. For Great Britain, raw estimates reduce that ratio by 60 percent. Using raw estimates and Great Britain as base country, the long-run power for changes in exchange rates is only 2.66 times larger than is consistent with purchasing power parity.

Table 3 also shows the averaged smoothed and raw estimates for $\Gamma_{\Delta s}(0.5)/\Gamma_{\Delta p}(0.0)$. For the United States, raw estimates reduce that ratio by 43 percent. For Great Britain, raw estimates reduce that ratio by 47 percent. Using raw estimates and Great Britain as base country, the short-run power in exchange rates is only slightly larger, 1.82, than is consistent with purchasing power parity.

With 24 years of data, the longest complete cycle we can see is 24 years. Estimates for all longer cycles are interpolations. If flexible exchange rates survive for another fifty years and the underlying data generating mechanisms do not change too much, in fifty years we should obtain much better estimates for the lowest frequencies. Given the decline in the evidence for excessive volatility seen here, I conjecture that, with a better understanding of purchasing power parity, better econometric techniques and a much longer data set, all of the evidence for 'excessive' volatility will disappear.

D. *Interpretation*

The main purpose of this paper is to show how the frequency domain can provide a better measure of relative volatility between exchange rates and relative price indexes. However the empirical results suggest some possible explanations for differences in relative volatility.

The decline in relative volatility when switching the base country from the United States to Great Britain suggests two complimentary explanations. First, the special role of the dollar may amplify dollar volatility. Second, economic distance may play a role.[17] The United States is relatively isolated from most of the countries in this sample. Great Britain is much closer to the continental countries. As a member of the European Common Market, she is also more highly integrated with many countries in the sample.

Another possible candidate for explaining relative volatility is differences in inflation. If the volatility of exchange rates rises either more slowly or more rapidly than the long-run volatility of relative price levels, the long-run volatility of relative price levels will affect the volatility of exchange rates relative to the volatility consistent with purchasing power parity.

Table 4
Long-Run Volatility of Exchange Rates

	All 39 Country Pairs	Excluding All Quarterly Data	Excluding Ireland-U.S, N. Z.-U.S., Austral.-G.B.
Intercept	0.71	1.43**	1.39**
	(0.47)	(0.32)	(0.30)
$\Gamma_{\Delta p}(0.0)$	2.23**	1.52**	1.50**
	(0.49)	(0.34)	(0.33)
Dollar	0.36	-0.30	-0.28
	(0.72)	(0.51)	(0.47)
Distance	3.47**	3.52**	3.59**
	(0.75)	(0.51)	(0.46)
Quarterly	0.98		-0.70
	(1.05)		(0.67)
$\bar{R}^2$	0.79	0.79	0.82

** Significant at the 1 percent level.

Table 4 shows the results of a cross section regression of the long-run volatility of exchange rates, $\Gamma_{\Delta s}(0.0)$, against the long-run volatility of relative price indexes, $\Gamma_{\Delta p}(0.0)$. Also included in the regression are a dummy for the dollar, a simple measure of distance, and whether or not the data are

[17] For some early evidence on the importance of distance for purchasing power parity see Davutyan and Pippenger (1990). For more recent evidence, see Engle and Rogers (2001) and Parsley and Wei (2001).

quarterly. The dummy Dollar is one for dollar exchange rates and zero otherwise. The dummy Distance is one when pairs of countries are separated by either the Atlantic or Pacific Ocean and zero otherwise. The dummy Quarterly is one when the data are quarterly and zero otherwise.

Using all 39 pairs of countries, the results in Table 4 suggest that neither the special role of the dollar nor the interval of the data are important for the long-run volatility of exchange rates. Coefficients for both Dollar and Quarterly are insignificant. However the other two variables explain almost 80 percent of the cross sectional variance in $\Gamma_{\Delta s}(0.0)$.

Distance is important. The coefficient for Distance is 3.47 and significant at the 1 percent level. Being separated by the Atlantic or Pacific increases the long-run volatility of exchange rates. The volatility of relative price indexes also is important. The coefficient for $\Gamma_{\Delta p}(0.0)$ is 2.23, which is significant at the 1 percent level. That coefficient is also significantly greater than 1.0 at the 5 percent level. For the full sample, a larger $\Gamma_{\Delta p}(0.0)$ increases $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$. However that result is not robust across countries.

The second column of estimates in Table 4 shows the results of excluding country pairs with quarterly data. There are two reasons for that exclusion. First, the dummy Quarterly may not completely compensate for mixing quarterly and monthly data. Second, three of the six quarterly series appear to be outliers with respect to the long-run volatility of exchange rates. To separate the effects of quarterly data and outliers, the third column of estimates shows the results of excluding just the outliers: Ireland-U.S., New Zealand-U.S. and Australia-Great Britain. The results in columns two and three show that the estimates are not sensitive to any of these exclusions. Most estimates of coefficients and levels of significance change very little.

However there is one important exception. The coefficients for $\Gamma_{\Delta p}(0.0)$ are no longer significantly greater than one. Once one excludes Ireland-U.S., New Zealand-U.S. and Australia-G.B., more volatility in relative price indexes does not significantly increase the volatility of exchange rates relative to the volatility consistent with purchasing power parity. A larger $\Gamma_{\Delta p}(0.0)$ no longer significantly increases $\Gamma_{\Delta s}(0.0)/\Gamma_{\Delta p}(0.0)$.

Table 5 below is the same as Table 4 except that it looks at the short-run volatility of exchange rates. That is, $\Gamma_{\Delta s}(0.5)$ rather than $\Gamma_{\Delta s}(0.0)$ is the dependent variable in Table 5.

The results in Table 5 are very different from those in Table 4. For one thing coefficients are sensitive to the choice of country pairs. Nothing but the intercept is significant when all quarterly data are excluded. For all 39 country pairs, the coefficient for Dollar is significant at the 1 percent level. However that significance disappears when Ireland-U.S., New Zealand-U.S. and Australia-Great Britain are excluded. On the other hand, the coefficient for Quarterly is significant when just Ireland-U.S., New Zealand-U.S. and Australia-Great Britain are excluded, but not otherwise. Distance is the most stable variable, but it is not always significant. Distance is significant only in the first and last column. When all quarterly data are excluded, distance is insignificant.

Table 5
Short-Run Volatility of Exchange Rates

	All 39 Country Pairs	Excluding All Quarterly Data	Excluding Ireland-U.S, N. Z.-U.S., Austral.-G.B.
Intercept	1.79**	1.75**	1.49**
	(0.29)	(0.23)	(0.29)
$\Gamma_{\Delta p}(0.0)$	-0.12	0.05	0.29
	(0.30)	(0.25)	(0.31)
Dollar	-1.35**	-0.26	-0.72
	(0.44)	(0.37)	(0.47)
Distance	1.80**	0.65	1.33**
	(0.46)	(0.37)	(0.44)
Quarterly	2.60		2.00**
	(0.64)		(0.64)
$\bar{R}^2$	0.64	0.05	0.53

** Significant at the 1 percent level

The most surprising result in Table 5 is that the long-run volatility of relative price levels does not affect the short-run volatility of exchange rates. The coefficient for $\Gamma_{\Delta p}(0.0)$ is insignificant in all three columns.[18] This result probably is due either to leaning against the wind by central banks or to

[18] When $\Gamma_{\Delta s}(0.5)$ is regressed against just an intercept and $\Gamma_{\Delta p}(0.0)$, $\Gamma_{\Delta p}(0.0)$ is significant at the 5 percent level with all the pairs of countries, but not otherwise.

some other stabilizing influence. Variation in that stabilizing influence apparently has broken the link between the long-run and short-run volatility in exchange rates that we would expect from an efficient market.

In Tables 1 and 2, the percentage decline from the second to third column shows the decline in power from long run to short run for exchange rates. That is, the decline reflects the percentage change from $\Gamma_{\Delta s}(0.0)$ to $\Gamma_{\Delta s}(0.5)$. If that decline were consistent across country pairs, we would expect $\Gamma_{\Delta p}(0.0)$ to affect $\Gamma_{\Delta s}(0.5)$ significantly in Table 5 because $\Gamma_{\Delta p}(0.0)$ affects $\Gamma_{\Delta s}(0.0)$ very strongly in Table 4.

However there is a wide range of stabilization within each table. In Table 1, the decline from $\Gamma_{\Delta s}(0.0)$ to $\Gamma_{\Delta s}(0.5)$ ranges from 15 percent for Canada to more than 75 percent for Ireland, Italy and Portugal. In Table 2, that decline ranges from a fall of 66 percent for Canada to an *increase* of 13 and 18 percent for Spain and Norway respectively. Large variations in the amount of short-run stabilization apparently destroyed any systematic link between $\Gamma_{\Delta p}(0.0)$ and $\Gamma_{\Delta s}(0.5)$.

SUMMARY

The primary evidence for believing that the volatility of flexible exchange rates is 'excessive' is that the variability of monthly changes in flexible exchange rates is much larger than the variability of monthly changes in relative price indexes such as CPIs. Using CPIs and the United States as the base country, for the period and countries covered here, the average ratio of the two variances is 42. Using Great Britain as the base country, the ratio is 12.

However using variances in that way seriously biases relative volatility upward. In addition, using variance does not allow us to distinguish between two very different sources for any additional volatility in exchange rates. The frequency domain, which decomposes variance by frequency, helps solve both problems.

Two factors combine to bias measures of relative volatility. First the two variances are not comparable in the sense that their spectral shapes are very different. Second, purchasing power parity is a long-run theory.

If standard price indexes used auction prices, then the spectrum for changes in relative price indexes would be fairly flat. In that case, the two variances would be comparable in the sense that the distribution of power across frequency would be similar. However sticky prices in standard price indexes cause changes in ratios of price indexes to have spectra that are relatively low at high frequency but that rise rapidly as frequency approaches zero.

Because purchasing power parity is a long-run theory, only part of the power in changes in relative price indexes is relevant. That power is the long-run power, *i.e.*, the power at the lowest frequencies. Since the power there is much larger than at higher frequencies, the variance for changes in relative price indexes seriously underestimates the volatility of relative price indexes that is consistent with purchasing power parity. Because of that underestimate, comparing variances seriously overstates the volatility of exchange rates relative to the volatility consistent with purchasing power parity.

Because the spectrum decomposes variance by frequency, using the frequency domain can reduce the bias from sticky prices. Using the frequency domain has another advantage. Decomposing variance by frequency allows us to identify two different sources for any remaining additional volatility in exchange rates.

With respect to the bias due to sticky prices, using the frequency domain substantially reduces, but does not eliminate, the evidence that flexible exchange rates are more volatile than is consistent with purchasing power parity. Because there is a short sample problem with post Bretton Woods data, a longer data set probably will eliminate more of the evidence for 'excessive' volatility.

With respect to the source of the additional volatility in exchange rates, the frequency domain suggests that neither overshooting nor some form of destabilizing speculation are the source of the additional volatility. Spectral estimates for changes in exchange rates do not rise as frequency increases as implied by overshooting and destabilizing speculation such as bandwagons. If there is any pattern, spectral estimates tend to fall slightly as frequency increases. That pattern suggests some stabilizing influence. One likely candidate is leaning against the wind by central banks.

If the additional volatility in flexible exchange rates is not due to overshooting or some form of destabilizing speculation, then that additional volatility presumably exists because economic fundamentals other than relative price levels affect exchange rates. If so, then it would be inappropriate to call such additional volatility 'excessive'.

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