REAL EXCHANGE RATES: HETEROSCEDASTICITY AND REVERSION TOWARD PPP

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Abstract

Previous attempts to reject the hypothesis that real exchange rates follow a random walk have produced mixed results. This paper incorporates mean reversion and conditional heteroscedasticity into tests based on a theoretical model of deviations from the law of one price by Dumas (1988). The results indicate that once conditional heteroscedasticity is incorporated into the estimation significant mean reversion cannot be rejected. The tests also point to substantial differences between the real exchange rate behavior of countries which are in the European Monetary System and those which are not.

The author is grateful to Bernard Dumas, Bob Cumby and the Penn Macro Lunch Group for useful discussions. Financial support from the Geewax-Terker Research Program in Financial Instruments is greatly appreciated. As usual, any remaining errors are my own.

Real Exchange Rates: Heteroscedasticity and Reversion Toward PPP

I. Introduction

The idea that deviations from purchasing power parity (PPP) follow a random walk originates with Roll (1979) and the concept of ex ante PPP. The argument behind the idea is essentially that due to the existence of risk neutral arbitragers and the possibility of storing goods, the relative prices of goods across countries must follow a martingale process in order to eliminate expected profits. The importance of the concept should not be underestimated because, if it is true, it implies that there is no long (or short) term tendency for PPP to hold, something of interest to both international financial and trade economists. Early tests of this hypothesis such as Roll (1979) and Adler and Lehman (1983) were unable to reject the random walk hypothesis for most countries.

One possibility for the lack of strong empirical evidence against the random walk hypothesis is that the alternative hypothesis is not well enough specified which leads to weak tests. Evidence pointing in this direction includes Mishkin (1984), Cumby and Obstfeld (1984) and Huizinga (1986). Each of these three papers incorporates a different technique for testing for a random walk. Mishkin tests for uncovered interest rate parity and ex ante PPP separately as well as jointly. While each of the hypotheses is not rejected when tested separately, a joint test of both is easily able to reject, presumably due to the increased power obtained from the joint test. Cumby and Obstfeld's test of ex ante PPP represents another innovation in that it allows the rational expectations projection errors to display conditional heteroscedasticity. As a result of this and the fact that they conduct a joint test of both the slope and intercept term in their regression equation, they report results which are "strongly at variance" with the hypothesis of ex ante PPP. Huizinga (1986) takes somewhat different approach from previous studies, abandoning the use of monthly changes in the real exchange rate in favor of a longer term analysis. His results suggest that mean reversion occurs in the long term.

Of the three tests just described, Mishkin and Cumby and Obstfeld seem to be able to provide evidence against a random walk solely on the basis of having more powerful test statistics. Huizinga, on the other hand, seems to benefit from the long-term nature of the test. None of the three tests, however, attempts to more carefully describe the actual process being followed by the real exchange rate on the basis of an alternative theoretical model. It is in this context that the recent theoretical model described in Dumas (1988) is helpful. In that model, deviations from PPP are an equilibrium phenomena but, because of the desirability of equalizing prices across countries, there is always a tendency for reversion toward PPP. This leads to a process for the real exchange rate which is both stationary and displays conditional heteroscedasticity. Due to the well specified nature of the process, tests which are based on it seem to be more powerful and, therefore, more able to reject the hypothesis of a random walk. This paper incorporates the process described by Dumas into tests of the stationarity of real exchange rates.

The remainder of the paper is organized as follows. In Section 2 a traditional test is presented which leads to the conclusion that the real exchange rate cannot be distinguished from a random walk. Section 3 describes the process developed in Dumas (1988) and presents the results of estimating an approximation to it. Under that specification, statistically significant mean reversion is documented. Conclusions are presented in Section 4.

2. A Test of the Random Walk Hypothesis

When foreign exchange markets are efficient, goods are storable and there are risk neutral arbitragers, then the real exchange should follow a random walk. If not, then arbitragers would be able to predict expected movements in the real exchange rate and conduct intertemporal arbitrage in the goods markets. The interested reader is referred to Roll (1979) for the development of the theoretical aspects of this idea of ex ante PPP, while Cumby and Obstfeld (1984) provide an informative development of the empirical content. A reported in the previous section, the evidence to date has been mixed on whether real exchange rates follow a random walk or if long (or short) term reversion toward PPP is the reality.

In order to demonstrate the type of results obtained in previous work, this section presents a test of the random walk hypothesis. The test is based on the empirical distribution of t-statistics for processes with unit roots and is commonly referred to as Dickey-Fuller test. It is a general test for unit roots under the assumption that the process is homoscedastic, which has been a maintained assumption in most of the previous tests.

For the tests conducted in both the current and subsequent sections, all data is taken from the International Financial Statistics. Real exchange rates are calculated using month-end nominal exchange rates and the consumer price indices for the two countries involved. Cumby and Obstfeld show that the use of wholesale price indexes produces essentially identical results. For non-U.S. bilateral rates, the exchange rate is inferred from the two dollar-foreign currency rates. All tests are conducted using 170 monthly observations beginning May, 1973.

In what follows, define the real exchange, y_t, be the

$$y_t \equiv e_t p_t^* / p_t$$

where e_t is the nominal exchange rate, p_t^* is the foreign price level and p_t is the domestic price level. A test of the random walk hypothesis can be based on the regression:

$$(1) \qquad y_t = \beta_0 + \beta_1 t + \beta_2 y_{t-1} + \beta_3(y_{t-1} - y_{t-2}) + \varepsilon_t$$

where t is a time trend and the null hypothesis is that $\beta_2 = 1$. The test is a simple t-test but, due to problems with nonstationarity under the null hypothesis, it must be based on the empirical distribution of the t-statistic presented in Fuller (1976). Results of the test for nine country pairs are presented in table 1.

The first five countries listed represent the real exchange rate between the U.S. and those five countries, whereas the remaining four country pairs present the results for the real exchange rate for those countries. In only one case, Germany/Netherlands, can the hypothesis of a random walk be rejected for either the real exchange rate or its logarithm. Note, however, that in all cases the value of β_2 is less than one, something required for stationarity and reversion toward PPP.

One possible explanation for the inability of this test to reject a random walk is that the hypothesized process is too general and that, as a result, the test has low power. One way to deal with this aspect of the problem is to more carefully specify the process which the real exchange rate is supposed to follow, something which is done in a recent theoretical model by Dumas (1988). The next section reviews that model and conducts further tests of mean reversion based on its predictions.

3. Test of Mean Reversion Based on Dumas (1988)

Dumas (1988) presents a theoretical model of a world economy in which deviations from the law of one price (LOP) are an equilibrium outcome. This section takes those theoretical results into consideration when estimating the process followed by the real exchange rate. For clarity, an explanation of the model is given before the tests are described. In order to be brief, the concentration here will be on the framework of the economy and the intuition behind the results. For an exposition of the technical details the reader is referred to the original paper.

The economy is developed in continuous time and is assumed to consist of two identical investor-consumers, each of which lives in a separate country and has preferences defined over the expected utility of consumption of the single good. Agents are risk averse and can consume the good only when it is physically present in their country, thus the good is distinguished by its physical location. At each point in time, agents possess a given amount of the good which must be allocated to either consumption or production. Goods not consumed are invested in a random constant returns to scale production process either at home or abroad (after shipping costs have been incurred). The same production process is available in both countries, except for a random productivity shock which is uncorrelated across countries. Goods not used locally can be transferred abroad for investment in the foreign production process; however, shipping is costly. Only a fraction of the amount shipped is available for production abroad. It is this fractional shipping cost combined with the risk aversion of agents which leads to an equilibrium in which deviations from the law of one price are observed.

Given well developed financial markets and symmetry across agents, equal stocks of capital in the two countries is optimal. Due to different output shocks, however, differences in the level of capital will develop and, with positive costs to shipping, these differences will persist. Generally, instead of shipping capital it is optimal for agents in the country with more capital to increase consumption so that, over time, the discrepancy is eliminated without shipping. Only when discrepancies become large enough will actual shipment of capital occur.

Under the assumptions of the model, a constrained Pareto optimal allocation exists and the relative price of capital in the two countries can be obtained from the ratio of the marginal utilities of capital. While the relative price function is not solved for explicitly, numerical approximations allow it to be characterized for certain preferences and parameter values. Without shipping costs, equilibrium would be characterized by equal values for capital in each country; however, when shipping is costly, the model finds that relative deviations from the LOP will exist and, more importantly for this paper, that those deviations will be characterized by both mean and reversion and conditional heteroscedasticity.

For reasons stated below, Dumas describes deviations from the LOP in relative terms through the transformed variable

$$\pi = (\rho - 1)/((\rho + 1)/2)$$

where ρ is the price of capital in the foreign country relative to the price of capital in the home country. In this paper, the real exchange rate, y_t, will be used for ρ. Two examples of the path followed by this variable over the sample period are presented in figures 1 and 2. Note that relative difference in the size of the deviations for the US/Japan as compared to the Netherlands/Germany. This difference in deviation is characteristic of the European Monetary System (EMS) and non-EMS country pairs for the entire sample group of country pairs. This apparent difference in the behavior of the EMS country pairs will manifest itself later in the tests as well.

Similar to tests of the random walk hypothesis, the tests in this section will be conducted using the first difference of π as the dependent variable. Evidence in support of the use of $\Delta\pi_t \equiv \pi_t - \pi_{t-1}$ is given in table 2 where sample statistics of $\Delta\pi_t$ and its correlation with the first difference of the natural logarithm of the real exchange rate (used in the previous tests cited in the introduction) are presented. In all cases the correlation between the two variables is in excess of 0.999 and the autocorrelation coefficients of $\Delta\pi_t$ are qualitatively very similar to those reported by Huizinga (1986) for the first difference of the logarithm of the real exchange rate. Unreported tests for a unit root in the variable π_t produced identical inferences to those reported in table 1 for the logarithm of the real exchange rate and almost identical values for the t-statistics.

Dumas chose to look at π rather than ρ as the measure of deviations from the LOP for two reasons. First, this measure of relative deviations has the advantage that it is symmetric with respect to the country considered to be the home country and, consequently, its drift and diffusion coefficient functions are symmetric. Second, it is mean zero since ρ is equal to one when the law of one price holds. Empirically, as will be seen below, the symmetry is helpful as it makes it relatively easy to specify functions which approximate the process.

From the model, it is found that the drift term and the diffusion coefficient of the generalized Ito process

$$d\pi = \alpha(\pi)dt + \sigma(\pi)dz \tag{2}$$

are approximately by the functions given in figures 3 and 4, where the symmetry mentioned above is readily apparent. In figure 3 it is seen that the drift term is increasing (in absolute value) in the relative deviation from the LOP. The sign of the drift is such that reversion toward the LOP occurs, with reversion occurring at a faster rate as prices deviate more and more from the LOP. For the diffusion coefficient, however, figure 4 shows that variance is highest when deviations from the LOP are smallest. Ultimately for sufficiently larger deviation, $\pm\gamma$, shipping occurs, the variance of the process becomes zero and the drift term becomes the dominant factor.

The goal of this paper is to incorporate these two ideas of increasing mean reversion and decreasing variance into estimates of the deviation from PPP. Note that there has already been a generalization of the model from the LOP to PPP with no attempt by either Dumas or this author to introduce either money or multiple goods into the model. Similarly, there will be a shift from continuous time processes to discrete time estimations. On a purely theoretical level both represent concepts not dealt with in the Dumas model; however, if goods markets are ultimately what drive real exchange rates, then the processes that occur in the two country world described by Dumas should be helpful in deriving more powerful tests of deviations from PPP.

In the remainder of this section, various tests of the process given by (2) will be conducted. These tests require some additional explanations which I address now. First, the results reported will be for the variable π_t. All regression analysis has been conducted on both π_t as well as the real exchange rate, y_t, with little difference in the results. Second, in the theoretical model, the PPP value of π_t is zero. In the actual time series used in this investigation, however, the sample mean of π_t is not equal to zero because price indices, not price levels, are used in calculating the real exchange rate. In order to capture the idea of deviations, the sample mean is substituted for zero.

While the process described in figure 2 is a nonlinear function, in what follows it will be assumed that the drift term is given by

$$\alpha(\pi) \equiv \alpha \times (\pi_{t-1}-\bar{\pi})$$

where α is a constant to be determined and $\bar{\pi}$ is the sample mean of π_t. This should provide a close approximation to the drift term described in figure 2, especially for small and medium size deviations. According to the Dumas model, the null hypothesis is that $\alpha < 0$.

Ignoring momentarily the heteroscedasticity implied by the theory, consider the OLS estimation of α in the equation

(3)
$$\begin{aligned}\pi_t-\pi_{t-1} &\equiv \alpha(\pi_{t-1}-\bar{\pi}) + \varepsilon_t \\ &\equiv -\alpha\bar{\pi} + \alpha\pi_{t-1} + \varepsilon_t \ .\end{aligned}$$

Table 3 presents the results of this estimation. While α is always less than zero, for only four countries out of nine can the hypothesis that $\alpha = 0$ be rejected. Estimates of equation (3) using the logarithm of the real exchange rate instead of π produced virtually identical values for α and its standard error. Note that because of the inclusion of the constant term in the regression under the null hypothesis, West (1987) shows that the OLS standard errors are normally distributed and the (possible) nonstationary of π_t has no effect on the distribution used in making inferences.

Given the theoretical presence of heteroscedasticity, OLS is no longer the best linear unbiased estimator. One possibility for an improved estimator is to use weighted least squares (WLS), where the form of the heteroscedasticity is chosen to be

(4)
$$\sigma(.) = (\pi_{t-1}-\bar{\pi})^{-1} \ .$$

Under this specification, the variance decreases as the deviations from PPP get larger. This is in line with the process described in figure 3, except that under (4) the variance never goes to zero and is infinite when PPP holds. Notice that under this specification π becomes a random walk when PPP holds, but is everywhere else stationary. The estimates of (3) using weighted least squares are presented in table 4.

As before, all of the estimates of α are negative; however, using WLS has increased (in absolute value) the value of α and all coefficients are now significantly different from zero. This change is not in all cases due to increases in the measure of mean reversion, α, since in only four of the nine cases is the point estimate of α greater (in absolute value) than the estimate implied by the values reported in table 1. Rather, it is the precision of the estimates due to the more carefully specified process which permits rejections of a random walk. The same thing is not true regarding the OLS estimates presented in table 3. In that case it is a combination of both changes in the point estimates and increased precision when WLS is used which leads to a rejection of nonstationarity. As mentioned above, note the difference in the size of the point estimates of α for the EMS country pairs. While this may possibly indicate a difference due to the operation of the EMS exchange arrangement, tests for serial correlation in the residuals indicate that WLS may not produce consistent estimates in two of the cases. As in the OLS estimates, WLS estimation using the logarithm of the real exchange rate instead of π produced virtually values for α and its standard errors.

One method which guarantees consistent estimates and allows for conditional heteroscedasticity more like that described in figure 3 is maximum likelihood estimation. The approximation to the variance process which will be used is given by

(5) $$\sigma(.) = \gamma^2 - (\pi_{t-1}-\bar{\pi})^2 .$$

This process allows the variance to go to zero whenever deviations from PPP reach an absolute value of γ, which is also a parameter to be estimated. The results of estimating (3) and (5) by maximum likelihood when the projection errors, ε_t, are normally distributed are presented in table 5. The estimation is conducted using a maximum likelihood routine from the software package Gauss, which employs a combination of algorithms for maximizing the sum of the logarithms of the likelihood function. In this estimation the first iteration employed the algorithm developed by Berndt, Hall, Hall and Hausman (BHHH) (1974). Subsequent iterations employed an algorithm developed by Broyden, Fletcher, Goldfarb and Shanno, except for the final iteration which again employed the BHHH algorithm. For more discussion on these algorithms the interested reader is referred to the Gauss manual.

With the exception of France, Japan and the United Kingdom, all of the estimated values of α are significantly below zero at the five percent level. The values of α do vary somewhat from the estimates obtained in the regressions, particularly for the EMS country pairs where the rate of reversion toward PPP is generally much higher for the maximum likelihood estimates than for the least squares estimates.

If shipping costs are indeed the determining factor in permitting deviations from PPP to occur, then it would seem that the physical proximity of the EMS countries (as well as the US/Canada and Germany/UK) would dictate that the estimated value of γ be lower for those countries. In fact this is exactly what happens. Note, however, the difference in γ for Germany/UK (as well as the high value of α), which would seem to be more related to the fact that the UK is not a member of the EMS exchange arrangement than to geographical location. It is also interesting that the values of γ for all countries versus the US are so close to 29 percent.

Unlike the EMS country pairs, the other exchange rates reported seem to underestimate the value of γ, as is seen for the US/Japan in figure 1. Relative deviations from PPP in excess of the estimated value of γ occurred in both 1978 and 1987. Similar relative deviations in excess of γ occurred for all but the EMS country pairs and Canada. While these "excess" deviations were generally brief, they do point to shortcomings in either the estimation technique, the assumed functional forms for α and σ, or the theoretical model. Future work, both theoretical and empirical, should try to account for the differences between the results obtained for the EMS and non-EMS country pairs.

4. Conclusion

Previous tests similar to the one in section 2 of this paper have been unable to reject the hypothesis that the real exchange rate follows a random walk. By using a more carefully defined null hypothesis, however, this paper has shown that the random walk hypothesis can be rejected and that reversion toward PPP occurs at varying rates depending on the countries involved. Mean reversion is generally greater between those countries that are members of the European Monetary System, with values as great as 16 percent per month occurring. Consequently, deviations from PPP over the sample period for EMS countries have been generally smaller, something which is surely in agreement with their objectives.

These results pose other questions which could lead to additional research in this area. For example, the results here seem to indicate that there is a significant difference between the process followed by the real exchange rate for EMS countries and non-EMS countries. Is this difference a result of the exchange rate arrangement that those countries share; or, as the US/Canada exchange rate suggests, is it geographical proximity or the economic importance of trade between the country pairs that causes the difference? Finally, are deviations from PPP limited to γ percent due to the possibility of shipping goods internationally, as in the Dumas model, or is the 29 percent rule simply an artifact of the same period? The answer to these questions may provide ammunition for those who favor more coordination among central banks regarding exchange rates, or they may simply reinforce the idea that both foreign exchange and goods markets are efficient and should be left alone by governments.

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Table 1

$$y_t = \beta_0 + \beta_1 t + \beta_2 y_{t-2} + \beta_3(y_{t-1} - y_{t-2}) + \varepsilon_t$$

	y_t		$\ln y_t$	
	τ_t	β_2	τ_t	β_2
Canada	-1.89	0.942	-1.80	0.947
France	-0.83	0.985	-0.87	0.985
Germany	-0.83	0.986	-0.91	0.984
Japan	-1.43	0.974	-1.33	0.976
Netherlands	-1.00	0.983	-1.07	0.982
United Kingdom	-2.04	0.973	-1.40	0.977
France/Germany	-2.69	0.927	-2.59	0.931
France/Netherlands	-3.05	0.919	-3.05	0.919
Germany/Netherlands	-3.72	0.909	-3.59	0.912
Germany/United Kingdom	-1.70	0.965	-1.57	0.969

Table 2

Sample Statistics for Relative Deviations from PPP

	$\Delta\bar{\pi}$	ρ_1	ρ_2	ρ_3	$\rho(\Delta\pi, \Delta \ln y)$
Canada	0.001 (0.014)	-0.095	-0.132	0.067	0.999
France	0.000 (0.033)	-0.064	0.139	0.055	0.999
Germany	0.000 (0.035)	-0.029	0.121	0.020	0.999
Japan	-0.002 (0.033)	0.093	0.039	0.139	0.999
Netherlands	-0.000 (0.035)	-0.050	0.172	0.004	0.999
United Kingdom	-0.006 (0.031)	0.070	0.161	0.029	0.999
France/Germany	-0.000 (0.017)	0.118	0.101	-0.003	0.999
France/Netherlands	-0.000 (0.017)	0.113	0.022	-0.087	0.999
Germany/Netherlands	-0.000 (0.011)	0.040	-0.156	-0.224	0.999
Germany/United Kingdom	-0.000 (0.031)	0.157	-0.025	0.034	0.999

Standard errors in parentheses

$\Delta\pi \equiv \pi_t - \pi_{t-1}$

$\Delta \ln y \equiv \ln(y_t) - \ln(y_{t-1})$

Table 3

$$\text{OLS: } \pi_t - \pi_{t-1} = \alpha\bar{\pi} + \alpha\pi_{t-1} + \varepsilon_t$$

	constant	α	R^2	Q
Canada	0.001 (0.001)	-0.017 (0.013)	0.01	71.2 (0.00)
France	0.000 (0.002)	-0.016 (0.014)	0.01	30.6 (0.83)
Germany	0.000 (0.003)	-0.016 (0.014)	0.01	28.5 (0.89)
Japan	-0.003 (0.003)	-0.016 (0.017)	0.01	39.4 (0.45)
Netherlands	-0.001 (0.003)	-0.015 (0.014)	0.01	35.0 (0.65)
United Kingdom	-0.007 (0.002)	-0.015 (0.007)	0.03	43.0 (0.30)
France/Germany	0.000 (0.001)	-0.050 (0.024)	0.02	67.4 (0.00)
France/Netherlands	-0.000 (0.001)	-0.064 (0.023)	0.04	47.2 (0.17)
Germany/Netherlands	-0.001 (0.001)	-0.064 (0.023)	0.04	64.3 (0.01)
Germany/United Kingdom	-0.001 (0.002)	-0.019 (0.015)	0.01	37.6 (0.53)

Standard errors in parentheses, except for Q where the probability of a higher value is in parentheses.

Table 4

$$\text{WLS:} \quad \pi_t - \pi_{t-1} = \alpha\bar{\pi} + \alpha\pi_{t-1} + \varepsilon_t$$

	constant	α	R^2	Q
Canada	-0.001 (0.001)	-0.026 (0.010)	0.04	67.9 (0.00)
France	0.002 (0.003)	-0.027 (0.011)	0.04	35.9 (0.61)
Germany	0.003 (0.003)	-0.028 (0.010)	0.04	36.9 (0.56)
Japan	-0.005 (0.003)	-0.046 (0.015)	0.05	46.3 (0.20)
Netherlands	0.002 (0.003)	-0.027 (0.010)	0.04	39.6 (0.44)
United Kingdom	-0.005 (0.002)	-0.017 (0.005)	0.08	41.9 (0.35)
France/Germany	0.001 (0.002)	-0.091 (0.019)	0.13	57.2 (0.03)
France/Netherlands	-0.002 (0.002)	-0.100 (0.020)	0.13	52.5 (0.07)
Germany/Netherlands	0.001 (0.002)	-0.110 (0.023)	0.20	59.2 (0.02)
Germany/United Kingdom	-0.002 (0.002)	-0.035 (0.011)	0.06	42.2 (0.33)

Standard error in parentheses, except for Q where the probability of a higher value is in parentheses.

Table 5

	α	γ
Canada	-0.042 (0.016)	0.185 (0.002)
France	0.000 (0.001)	0.284 (0.000)
Germany	-0.024 (0.006)	0.292 (0.000)
Japan	0.016 (0.011)	0.254 (0.001)
Netherlands	-0.015 (0.006)	0.292 (0.001)
United Kingdom	-0.006 (0.006)	0.293 (0.000)
France/Germany	-0.160 (0.019)	0.172 (0.003)
France/Netherlands	-0.157 (0.026)	0.161 (0.003)
Germany/Netherlands	-0.034 (0.012)	0.112 (0.001)
Germany/United Kingdom	-0.130 (0.023)	0.328 (0.003)

Standard errors in parentheses.

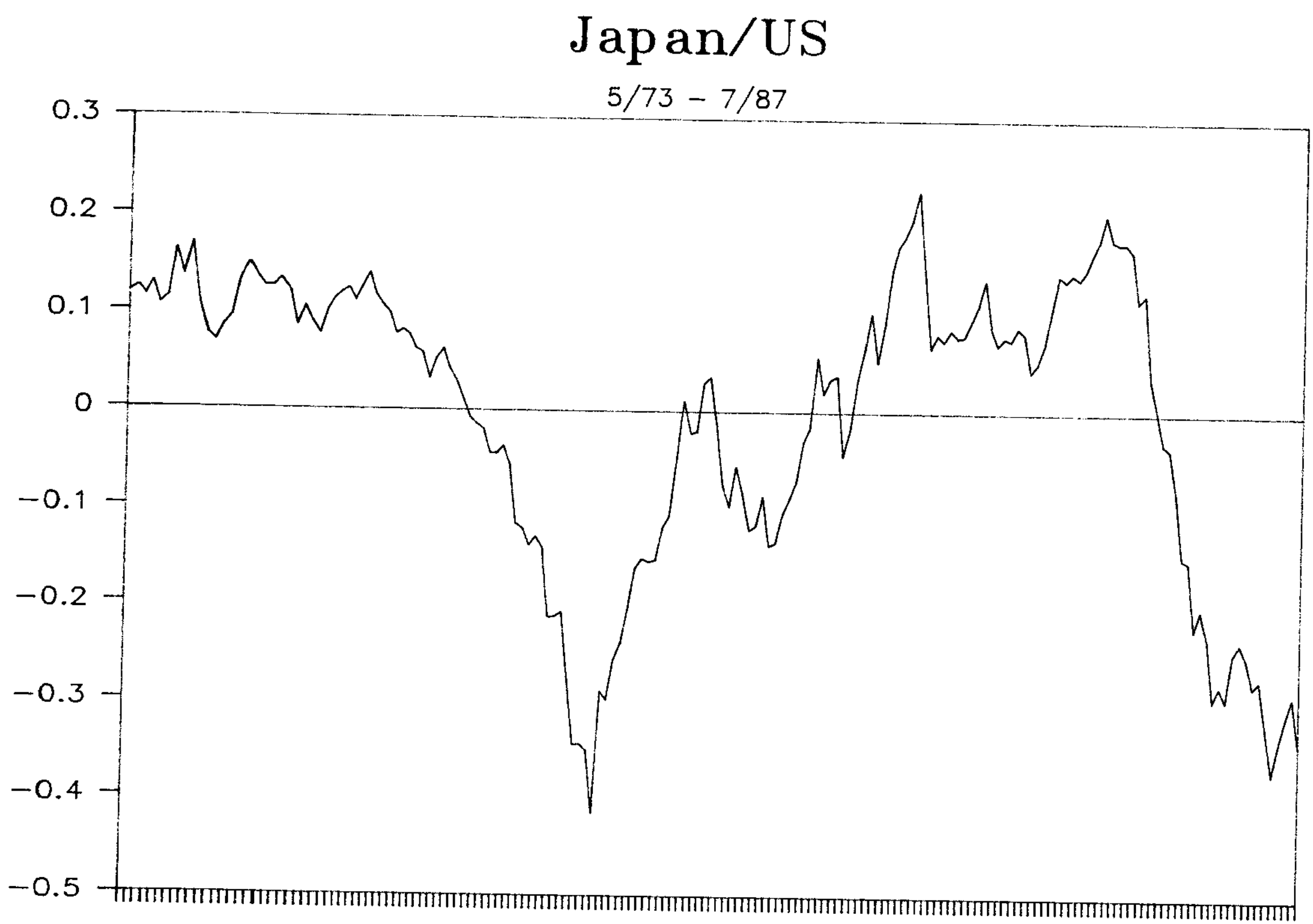
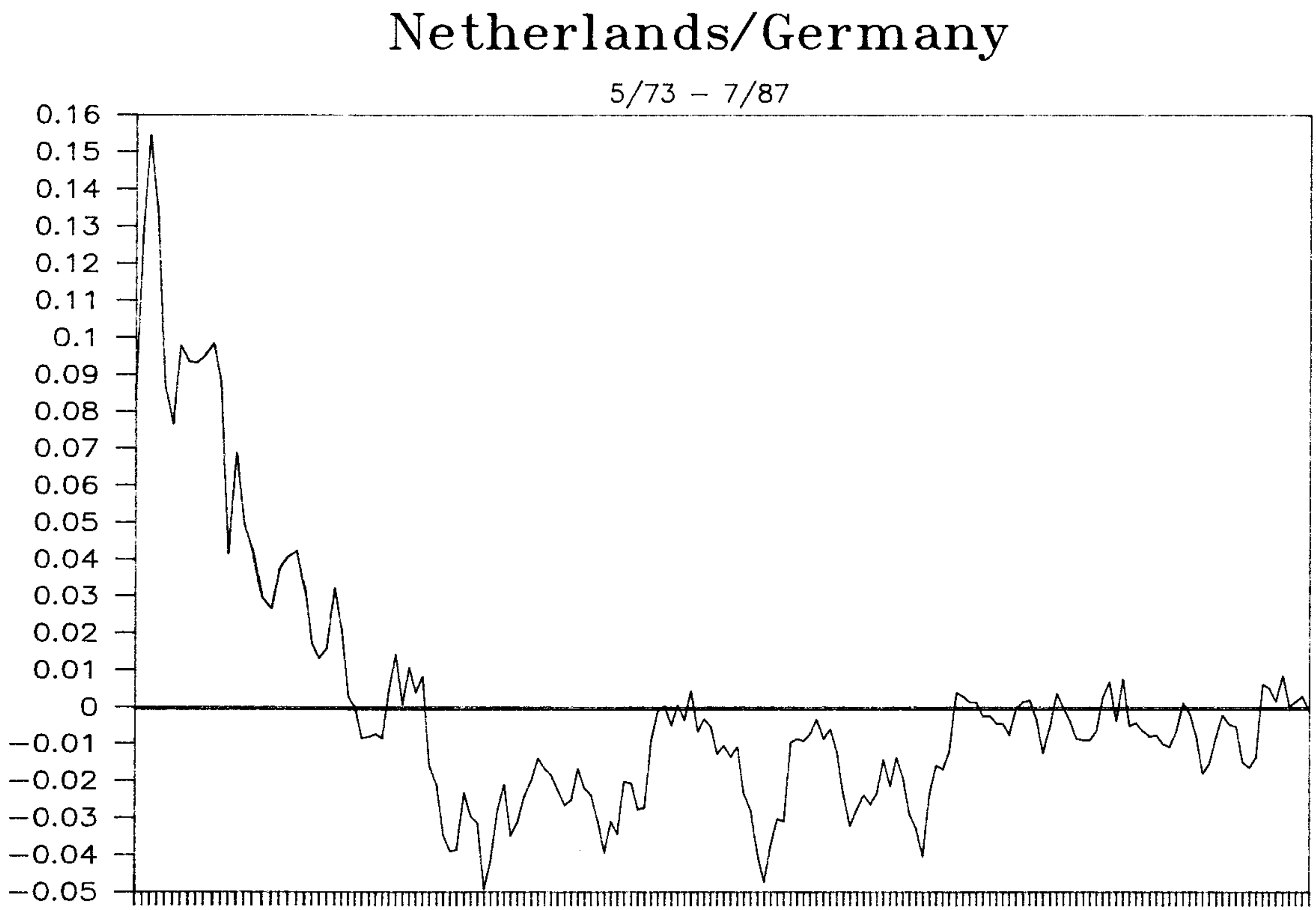


Figure 1


Netherlands/Germany
5/73 – 7/87
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−0.01
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−0.03
−0.04
−0.05

Figure 2

Figure 3

Drift of π

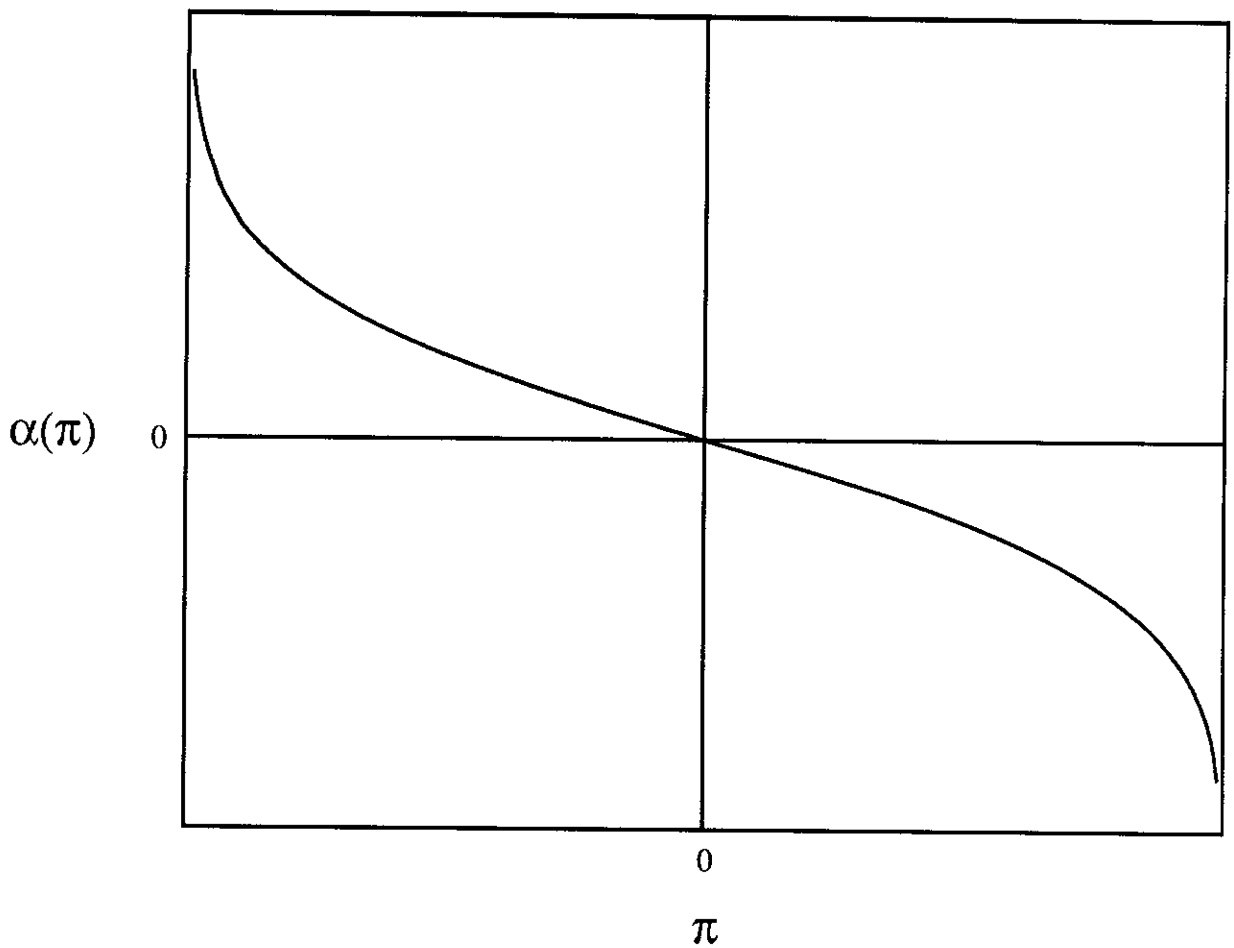

Figure 4

Standard Deviation of π