Exchange Rate Cointegration Across Central Bank Regime Shifts

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ABSTRACT: Foreign exchange rates are examined using cointegration tests over various time periods linked to regime shifts in central bank behavior. The number of cointegrating vectors varies across these regime changes within the foreign exchange market. For example, cointegration is generally not found prior to the Plaza Agreement of September 22, 1985, but it is present after that date. The significance of these changes is tested using a likelihood ratio procedure proposed by Quintos (1997). The changing nature of these cointegrating relationships indicate that certain types of central bank activity do have long-term effects on exchange rates.

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I. Introduction

> "Nevertheless, the empirical evidence, although allowing for the possibility of short-lived effects, does not ascribe to [central bank] intervention a long-lasting effect on the foreign exchange market." - Edison (1993)

The above quote is the concluding sentence of Edison's recent survey on the efficacy of central bank intervention in the foreign exchange market. The short-term impact of central bank intervention has been extensively studied, even down to the level of continuous time data (Goodhart and Hosse, 1993). However, the long-term impact of central bank behavior in the foreign exchange market has not been carefully examined. Several papers, such as Engel and Hamilton (1990) as well as Mark (1995), have examined the long-term behavior of exchange rates, but they do so without referencing regime shifts in central bank behavior, such as the Plaza Agreement of 1985. In this paper, the long-term impact of such regime shifts is examined using cointegration techniques.

Cointegration, as introduced by Engle and Granger (1987), is used to test for the existence of long-term relationships among nonstationary economic variables. Exchange rates are considered to be nonstationary time series, as first established by Meese and Singleton (1982), and systems of exchange rates may exhibit cointegrating relationships. However, as suggested by Granger (1986), financial asset prices determined in efficient markets should not be cointegrated, since one could forecast a given series on the basis of other series in the cointegrated system. Several studies have tested for cointegration in systems of foreign exchange rates, such as Hakkio and Rush (1989), Coleman (1990), Copeland (1991), Baillie and Bollerslev (1989, 1994), and Diebold *et al.* (1994).[1] Using various cointegration testing procedures, these studies achieve different results. For example, Baillie and Bollerslev (1989) find cointegration in

[1] Several papers, such as Baillie and Selover (1987) as well as Papell (1997), examine cointegration in systems of foreign exchange rates and other macroeconomic variables. The focus here, however, is on systems of foreign exchange rates only.

a system of seven daily exchange rates, but Diebold *et al.* (1994) find no cointegration in this system once a trend is explicitly modeled. Baillie and Bollerslev (1994) find evidence of fractional cointegration in the exchange rate system they examine.

This paper attempts to extend these studies by incorporating structural breaks in the cointegration analysis. Such breaks may significantly alter the equilibrium relationships between data series, and tests of the long-term behavior of these series should take account of them.[2] The breakpoints examined here are linked to specific regime shifts in central bank behavior toward foreign exchange rates. As opposed to previous studies that limited central bank activities to intervention (i.e., official sales or purchases of foreign assets against domestic assets), this paper focuses instead on actions or official announcements by central banks that indicate a regime shift in their behavior. Examples of such activities are the formation of the European Monetary System in March 1979 and the Plaza Agreement of September 1985. Five such episodes are examined in this paper.

With respect to the cointegration analysis, such regime shifts may be considered structural breaks that fundamentally alter any long-term equilibrium relationships that may exist. Thus, the number of cointegrating vectors present in the periods before and after a specified structural break may differ. Quintos (1997) proposed a procedure for testing whether such differences in the number of cointegrating vectors induced by structural breaks are statistically significant. The procedure specifically addresses structural breaks that potentially change a system's equilibrium relationships, such as fundamental changes in the behavior of institutions like central banks.

The main finding of this paper is that the specified incidents of central bank regime shifts do impact the long-term behavior of exchange rates. Varying numbers of cointegrating

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[2] Granger and Escribano (1986) find evidence that exceptional events in the gold and silver markets cause these two price series, which should not be cointegrated under the efficient markets hypothesis, to be cointegrated during certain time periods.

relationships are found before and after the structural breaks, and the changes are mostly found to be significant. For example, no cointegrating relationships are found in the period before the Plaza Agreement of September 22, 1985, but after that date, evidence of cointegration is found. Since the Plaza Agreement signaled concerted intervention by central banks to cause a dollar depreciation, it is not surprising that new long-term relationships between exchange rates arose in the post-Plaza period. Similar results are found for other breakpoints and for a subsystem of exchange rates consisting solely of European Monetary System (EMS) currencies.

Section II describes the exchange rate data used as well as the proposed structural breaks examined. Section III outlines the cointegration techniques used in the analysis. Section IV summarizes the literature on cointegration tests of exchange rates and presents the cointegration results for the various specified time periods and currencies. Section V concludes.

II. Data and Structural Breakpoints

The daily spot exchange rates used in this paper are the midpoints of the bid and ask rates recorded at noon in the New York foreign exchange market by the Federal Reserve Bank of New York. The data span the period from the beginning of 1974 through year-end 1991 for a total of 4513 trading days. The eight exchange rates examined are the British pound (BP), the German mark (DM), the Japanese yen (JY), the French franc (FR), the Swiss franc (SF), the Canadian dollar (CD), the Dutch guilder (NG) and the Italian lira (LI); see Figures 1 to 8. The first six exchange rates are historically the most actively traded, as per various central bank surveys; see Federal Reserve Bank of New York (1992) and Bank for International Settlements (1998). The NG and LI series are included to permit further analysis of the EMS currencies. The spot exchange rates are expressed as the natural log of foreign currency units per U.S. dollar.

Since cointegration tests examine the long-term behavior of economic data, the length of the “long term”, as discussed by Hakkio and Rush (1991), is an immediately relevant question.

They argue that the proper length of the "long term" must be determined in light of the economic question being addressed. Two sets of factors can be used to determine the proper time interval over which to examine exchange rates. With regard to market-based factors, the massive daily trading volume in this market would suggest that new information is quickly incorporated into exchange rates and that a rather short period of calendar time can be used as the "long-term" horizon of exchange rate determination. With regard to forecasting concerns, forecasts based on daily data are usually made only several months ahead, as in Diebold *et al*. (1994). Given these two reasons, time periods longer than one year (approximately 250 observations) would seem to be appropriate horizons over which to examine the long-term behavior of daily exchange rates. As shown in Table 1, the principal time periods examined here meet this criterion.

In addition to a period's length, the choice of its endpoints is also important. With respect to cointegration tests, Sephton and Larsen (1991) conclude that the evidence for cointegration is "fragile" and exhibits "temporal sensitivity" since different subsample periods provide differing results. Given this result, testing for cointegration over an arbitrarily chosen time period does not seem appropriate.

An alternative method for selecting a period's endpoints is to impose structural breaks exogenously in the spirit of Perron (1989). In this paper, the endpoints of the 18-year period from 1974 to 1991 are determined by an approximation to the start of the current floating-rate regime, which actually began in March 1973, and by data availability. The five proposed structural breaks are linked to regime shifts in central bank behavior with respect to foreign exchange rates.

The first breakpoint suggested is November 1, 1978.[3] On that date, a so-called "dollar-rescue package" was enacted by the U.S. to at least halt the depreciation of the dollar. The

[3] This breakpoint is explicitly examined in Loopesko (1984). In-depth summaries of the events surrounding all five breakpoints are provided in Dominguez and Frankel (1993).

package consisted of tightened monetary policy and the creation of an intervention fund. The ensuing sustained and coordinated intervention temporarily raised the value of the dollar, but it returned to its previous level by year end. The outcome of this intervention was interpreted to mean that substantial effects could be achieved, but that these effects would be temporary unless supported by genuine policy changes. This change in central bank behavior is included in the subsequent analysis to determine whether it did have a long-term impact.

The second proposed breakpoint, March 13, 1979, marks the formation of the European Monetary System (EMS). The original members agreed to fix their mutual exchange rates within certain bands and float jointly against the dollar. Although other exchange rate agreements had existed amongst European currencies, the EMS marked the formation of a new and more strongly codified system.

The third suggested breakpoint, February 25, 1985, primarily arises from the data. Five of the six European exchange rates achieve their post-1973 maximum on that day, and the sixth (SF) achieves its post-EMS maximum eight days later on March 5, 1985. According to financial news reports at the time, market participants could not cite any particular event that led to the dollar's rapid depreciation. However, the German Bundesbank and other European central banks, as well as the Federal Reserve to a lesser extent, intervened heavily throughout the first quarter of 1985 to halt the appreciation of the dollar. This intervention activity by the U.S. was directly linked to the change in the U.S. Secretary of the Treasury; Secretary Brady was willing to intervene while Secretary Regan was not. Most of these intervention operations were widely reported and signaled the central banks' intentions to market participants.

The fourth breakpoint examined is September 23, 1985, the first trading day after the announcement of the Plaza Agreement. In this agreement, the G-5 central banks stated that "some further orderly appreciation of the main non-dollar currencies against the dollar is desirable" and that they would "stand ready to cooperate more closely to encourage this when to do so would be helpful."[4] After this announcement, the dollar continued its prolonged depreciation as central banks intervened actively in the foreign exchange markets.

The fifth breakpoint is February 22, 1987, the day after the Louvre Accord. The G-7 central banks, excluding Italy, "agreed to cooperate closely to foster the stability of exchange rates around current levels."[5] In essence, the central banks agreed to stop the depreciation of the dollar and maintain a reference range for the major non-dollar currencies by intervening in the market, as necessary.

Given the dataset's endpoints and these five breakpoints, the data can be subdivided for our analysis into 11 periods: the entire post-1973 period; the pre- and post-"dollar rescue" periods; the pre- and post-EMS periods; the pre- and post-peak periods; the pre- and post-Plaza periods; and the pre- and post-Louvre periods. Table 1 lists the endpoints and the number of observations for each period, and Figure 9 provides a graphical representation of the periods.

III. Overview of Cointegration Techniques

A. Unit Root Test Results

Cointegration examines the relationships between nonstationary, I(1) variables. The nonstationarity of post-1973 exchange rates was initially documented by Meese and Singleton (1982) and has been verified by many authors. In this paper, augmented Dickey-Fuller and Phillips-Perron tests are used to examine the nonstationarity of exchange rates. The unit root tests are applied to the eight exchange rates in all 11 periods, and the null hypothesis of unit root behavior cannot be rejected in almost all time periods at the 1% and 5% levels.[6] The only period

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[4] G-5 Announcement of September 22, 1985. The G-5 countries are Britain, France, Japan, the U.S. and Germany.

[5] G-7 Announcement of February 22, 1987. The G-7 countries are the G-5 countries plus Canada and Italy.

[6] For purposes of space, the unit root tests are not presented, but are available upon request.

in which the unit root hypothesis may be rejected is the post-peak period. Given these results and standard practice in the literature, the various exchange rates are considered to be I(1) variables.

B. The Johansen Procedure

Various tests for the presence of cointegration amongst I(1) variables have been proposed beginning with Engle and Granger (1987). The procedure used in this paper is a multivariate procedure based on maximum likelihood methods introduced by Johansen (1988,1991) and expanded upon by Johansen and Juselius (1990). The procedure is based on a vector autoregressive model of X_t, an (nx1) vector of I(1) time series. The error-correction form is written in first differences as

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \ldots + \Gamma_{k-1} \Delta X_{t-k+1} + \Pi X_{t-k} + \mu + + \varepsilon_t$$

$$\varepsilon_t \sim N(0,\Lambda) \quad t = 1,\ldots T,$$

where Γ_i for i=1...k-1 and Π are (nxn) matrices, μ is a (nx1) vector of constants, ε_t is a (nx1) error vector and Λ is its (nxn) covariance matrix. Since ΔX_t is an I(0) process, the stationarity of the right side of the equation is achieved only if ΠX_{t-k} is stationary.

The Johansen procedure examines the rank of Π, which determines the number of cointegrating vectors present in the system. If rank(Π) = r < n, then $\Pi = \alpha\beta'$, where both α and β are (nxr) matrices. β is the matrix of cointegrating vectors, and the number of such vectors is r. Since the cointegrating vectors have the property that $\beta_j' X_t$, j=1,...,r is stationary, then the system is stationary. The cointegrating vectors are said to represent the long-term relationships present in the system.

The trace statistic is used in this paper to test the null hypothesis that rank(Π) = r against the alternative hypothesis that rank(Π) = n. Equivalently, the trace statistic tests whether r cointegrating vectors are present in the system against the alternative hypothesis that the system is already stationary (i.e., n cointegrating vectors are present in the system). The null hypothesis is tested under the assumption that $\mu \neq 0$. The trace statistic is a likelihood ratio (LR) statistic of the form

$$tr(r) = -T \sum_{i = r+1}^{n} \ln\left(1 - \hat{\lambda}_i\right),$$

where the $\hat{\lambda}_i'$s are the ordered solutions to the eigenvalue problem $\left|\lambda S_{kk} - S_{k0} S_{00}^{-1} S_{0k}\right| = 0.$ The S_{ij} matrices are the residual moment matrices derived from the postulated error-correction model. The distributions of the various forms of the trace statistic depend only on (n-r) and are tabulated in Osterwald-Lenum (1992).

C. The Quintos Procedure for Testing Rank Constancy

Quintos (1997) proposed a procedure for testing the rank constancy of the cointegrating matrix Π over sample subperiods; that is, the procedure tests whether the number of cointegrating vectors varies across sample subperiods. If the rank does vary, then the number of long-term relationships in the economic system changes across the breakpoint. The relevant test statistics are simply weighted averages of trace statistics for the subperiods, where the weights are the subperiod sample sizes. The test procedure is briefly summarized below.

The Quintos procedure permits one to test a wide variety of null hypotheses, but only a small subset of the available options are tested in this paper. For example, the procedure allows for J structural breaks in the system, but throughout this paper, J is set to one; see Quintos (1995). Furthermore, the procedure allows the breakpoints to be endogenous to the process, but in this paper, the breakpoints used will be exogenously imposed as in Perron (1989).

The main hypothesis tested in this paper is that the number of cointegrating vectors remains constant across the breakpoint; that is, $H_0^q : q_1 = q = q_2$, where q is the number of cointegrating vectors in the entire period, q_1 and q_2 are the number of cointegrating vectors in the pre- and post-breakpoint periods, and $0 \leq q < n$. Note that the coefficients of Π are allowed to vary across subperiods. Different LR statistics are used for the different permutations of the ranks of the full and subperiod Π matrices. For $q < q_1$ and $q < q_2$, the LR statistic is

$$LR = -p_1 \sum_{i=q+1}^{q_1} \ln\left(1 - \hat{\lambda}_{1i}\right) - p_2 \sum_{i=q+1}^{q_2} \ln\left(1 - \hat{\lambda}_{2i}\right),$$

where p_1 and p_2 are the number of observations in each subperiod and the $\hat{\lambda}_{ji}$, j=1,2 are the eigenvalues of the respective, estimated Π matrices. The distribution of this statistic is a function of scaled, n-dimensional Brownian motions and depends upon the variables n, q, q_1 and q_2. For $q > q_1$ and $q > q_2$, the relevant LR statistic is

$$LR^{\#} = p_1 \sum_{i=q_1+1}^{q} \ln\left(1 + \lambda_{1i}\right) + p_2 \sum_{i=q_2+1}^{q} \ln\left(1 + \hat{\lambda}_{2i}\right),$$

which is distributed $\chi^2_{(2q - q_1 - q_2)n}$. These statistics can also be used in case of an equality between q and either of the subperiod ranks. For the case $q_1 < q < q_2$, the LR statistic is

$$LR_1^* = -p_1 \sum_{i=q_1+1}^{q} \ln\left(\hat{\lambda}_{1i}\right) - p_2 \sum_{i=q+1}^{q_2} \ln\left(1 - \hat{\lambda}_{2i}\right),$$

and for the case $q_2 < q < q_1$, the LR statistic is

$$LR_2^* = -p_1 \sum_{i=q+1}^{q_1} \ln\left(1 - \hat{\lambda}_{1i}\right) + p_2 \sum_{i=q_2+1}^{q} \ln\left(1 - \hat{\lambda}_{2i}\right).$$

Both of these statistics have distributions that are mixtures of a χ^2 distribution and a function of scaled Brownian motions.

IV. Empirical Results

A. Previous Cointegration Tests of Exchange Rates

Five studies have directly tested for the presence of cointegration in systems of foreign exchange rates: Hakkio and Rush (1989), Coleman (1990), Copeland (1991), Baillie and Bollerslev (1989) and Diebold *et al.* (1994). The first three explicitly test for the efficiency of the foreign exchange markets; as mentioned before, the presence of cointegration among exchange rates would contradict the efficient markets hypothesis by implying that current rates can be predicted by past deviations from the long-run cointegrating relationships. The second two papers focus on modeling and forecasting exchange rates.

Hakkio and Rush (1989) use the Engle-Granger cointegration procedure to examine monthly spot rates for BP and DM from July 1975 to October 1986. They conclude that the two rates are not cointegrated at the 5% significance level, a result consistent with the market efficiency hypothesis. However, further tests involving the error-correction representation of the system leads the authors to reject the market efficiency hypothesis for these two currencies. Coleman (1990) uses the Engle-Granger procedure on daily data from 1973 to 1989 and finds no evidence of cointegrating relationships in the pairwise results for 18 currencies. Copeland (1991) examines bivariate systems of exchange rates for cointegration using the Johansen (1988) procedure. The data used is daily spot rates for BP, DM, JY, FR and SF over the period 1976 to 1990. Copeland finds no cointegration among the ten currency pairs at the 5% significance level, which supports the efficient market hypothesis.

Baillie and Bollerslev (1989) examine daily opening spot rates from the New York market for the period March 1, 1980 to January 28, 1985. The seven currencies used are BP, DM, JY, FR, LI, SF and CD. One cointegrating vector is found in this system using the Johansen procedure with $\mu=0$. They conclude that the deviations from the long-term relationship between these spot rates is an important component of the next period's observed rates; thus, the efficient markets hypothesis is violated. However, using the Johansen procedure with $\mu \neq 0$, Diebold *et al.* (1994) find no cointegration in this dataset. Furthermore, in a forecasting exercise, the authors find no improvements in forecast performance by the fitted error-correction model relative to the simple martingale model. A similar result is found for the entire post-1973 period.

The cointegration tests in this paper extend the latter two results by using a longer time period and a larger currency system. Furthermore, a subsystem of exchange rates consisting of the four EMS currencies is tested for the presence of cointegrating vectors. This cointegration analysis incorporates the structural breaks discussed in Section II. The cointegration results are derived using the Johansen procedure with $\mu \neq 0$ and the 5% critical values from Osterwald-Lenum (1992). The Quintos procedure described in Section III is applied to these cointegration results to determine whether the number of cointegrating vectors changed significantly between the pre- and post-breakpoint periods.

B. Cointegration Test Results: Post-1973 Period

To test for cointegration, error-correction models are fit to the two exchange rate systems under study, all eight currencies and the subset of EMS currencies. The lag orders of the models are determined by minimizing the multivariate Schwarz information criterion (SIC).[7] In both cases, the lag order chosen is two; that is,

$$\Delta X_t = \Gamma_1 \Delta X_{t-1} + \Pi X_{t-2} + \mu + \varepsilon_t.$$

The 11 time periods, as determined by the five structural breakpoints discussed in Section II as well as the entire post-1973 period, are tested for the presence of cointegration. A summary of these cointegration results is presented in Table 2. The results of the cointegration analysis for the full system of exchange rates are presented in Tables 3 to 13, and the results for the EMS subsystem are in Tables 14 to 24.

Two significant results arise from this analysis. First, for the entire post-1973 period, one cointegrating vector is found; thus, indicating that this system of exchange rates has at least one long-term cointegrating relationship. This result differs from that of Diebold *et al*. (1994) which excludes the Dutch guilder (NG) from the analysis. Second, the cointegration results for the pre-

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[7] To conserve space, the model estimation results are not presented. The various SIC statistics and the estimated parameters are available upon request.

breakpoint periods generally indicate the absence of any long-term relationships, except for the pre-EMS period. However, the post-breakpoint periods generally indicate the presence of one or more cointegrating relationships, with the exception of the post-Louvre period. These results seem to indicate that the “dollar rescue”, peak and Plaza breakpoints change the nature of the underlying long-term relationships in the foreign exchange market; these regime shifts in central bank behavior had a long-term impact on the exchange rates. It seems that the EMS breakpoint did not have an impact on the entire system of exchange rates.

These results indicate that the equilibrium relationship found in the entire post-1973 period has not necessarily remained constant. The varying number of cointegrating vectors in the pre- and post-breakpoint periods indicates that the underlying market equilibria for this system of exchange rates are affected by these structural breaks. To further explore the impact of these structural breaks, a subsystem of EMS currencies (i.e., DM, FF, NG and LI) is tested for the presence of cointegration. The results of the cointegration analysis for the EMS subsystem are different from those of the full system. At least two cointegrating relationships are indicated over the entire post-1973 period for this subsystem. In addition, cointegration is present in all subperiods, except for the pre-Plaza period and the pre- and post-Louvre periods. Overall, these results seem to indicate that the cointegration present in the entire system is probably driven by the cointegration present in the EMS subsystem.

C. Quintos Rank Constancy Tests

To determine whether these differences in the number of cointegrating vectors are significant, the Quintos tests described in Section III are applied to the cointegration results.

(i). Full System of Exchange Rates

Table 25 contains the results of the Quintos tests applied to the cointegration results for the full system of exchange rates over the entire post-1973 period. For all cases, other than the EMS breakpoint, the null hypothesis of rank constancy with unstable coefficients is rejected. Several implications immediately follow from these results. The most prominent is that these episodes of central bank intervention did have an impact on the long-term relationships (or equilibria) in this system of exchange rates. Thus, certain central bank activities can have a long-term impact on the foreign exchange market.

The meaning of these results for the individual breakpoints requires further study. The "dollar rescue" package, as described in Section II, did not have a strong impact on the market since shortly after its enactment, the market countered all of the gains the package provided. Yet, according to the Quintos test results, the cointegrating relationships across this breakpoint did change. On the other hand, the EMS breakpoint, which one would expect to have an impact on the system since it explicitly imposes a long-term relationship on the exchange rates, does not change the rank of the cointegrating matrix. The results for the peak, Plaza and Louvre breakpoints are as expected; these breakpoints seem cause a significant change in the cointegrating relationships in the system. Furthermore, the similarity between the peak and Plaza breakpoints is as expected.

To supplement these full-period results while recognizing the drop in power due to reduced sample size, subperiods around these breakpoints are examined in order to isolate the effects of a single breakpoint. The relevant test results are contained in Table 27.[8] This subperiod analysis seems to cast some light on the impact of the "dollar rescue" breakpoint. Although the null of rank constancy with unstable coefficients is rejected for the start-EMS breakpoint period, it cannot be tested for the longer start-peak and start-Plaza breakpoint periods. This result seems to indicate that the "dollar rescue" breakpoint had little overall impact and that

[8] Again, to conserve space, only the Quintos test results are reported. Complete subperiod estimation and cointegration test results are available upon request.

its impact with respect to the entire post-1973 period is mainly due to the events surrounding the peak and Plaza breakpoints. However, the results for subperiods surrounding the EMS, peak and Plaza breakpoints indicate that they did impact the system's cointegrating relationships.

(ii). EMS Subsystem of Exchange Rates

Table 26 contains the results of the Quintos test applied to the cointegration results for the EMS subsystem of exchange rates over the entire post-1973 period. For all cases, the null hypothesis of rank constancy with unstable coefficients is clearly rejected. Several implications follow from this set of results. The proposed central bank regime shifts seem to have an impact on the long-term relationships present in this subsystem of exchange rates. The "dollar rescue" breakpoint results are mixed in that the null hypothesis is rejected at the 5% significance level but not at the 1% level. The result that the "dollar rescue" period may not impact the EMS subsystem as strongly as the whole system is understandable since the event did not focus specifically on the EMS currencies.

To supplement these results, subperiods around these breakpoints are examined as before, while acknowledging the decline in power due to reduced sample size. The results of this analysis are contained in Table 28. The interesting result here regards the Plaza breakpoint. The subperiods examined for this breakpoint begin at the four previous breakpoints and end at the Louvre breakpoint; i.e., the post-Louvre period is excluded from the analysis. For the first three startpoints, $q = q_1 = q_2$; thus, the null of rank constancy cannot be rejected. For the subperiod starting at the peak breakpoint, the null can be rejected. These results seem to indicate that, for the EMS subsystem, the effects of Plaza breakpoint were not as strong as for the whole system.

<u>V. Conclusions</u>

The long-term impact of central bank activities, broadly defined, on the foreign exchange market is an issue that has not been directly examined. This paper attempts to address this question using cointegration analysis that incorporates structural breaks linked to specific regime shifts in central bank behavior. The five breakpoints examined are instances of changes in central bank behavior that may have substantially altered the long-term relationships among the eight currencies examined.

Using the Johansen procedure, cointegrating relationships are found for the full system of exchange rates and a subset consisting of four EMS currencies. The number of cointegrating vectors in the periods before and after the suggested breakpoints are found to be different in several cases. Furthermore, these differences are found to be statistically significant using the testing procedure proposed by Quintos (1997). Structural changes of the type that alter the definition of the system's equilibria seem to have occurred at these breakpoints. Thus, regime shifts in central bank behavior do have a long-term impact on foreign exchange rates.

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Table 1: Summary of the 11 Time Periods Examined

	Start Date	End Date	Observations
Post-1973 Period	01/04/74	12/31/91	4513
Pre-“Dollar Rescue” Period	01/04/74	11/01/78	1213
Post-“Dollar Rescue” Period	11/02/78	12/31/91	3300
Pre-EMS Period	01/04/74	03/13/79	1301
Post-EMS Period	03/14/79	12/31/91	3212
Pre-Peak Period	01/04/74	02/25/85	2791
Post-Peak Period	02/26/85	12/31/91	1722
Pre-Plaza Period	01/04/74	09/20/85	2938
Post-Plaza Period	09/23/85	12/31/91	1575
Pre-Louvre Period	01/04/74	02/20/87	3291
Post-Louvre Period	02/23/87	12/31/91	1222

Table 2:

Summary of the Johansen Cointegration Results for the Systems of FX Rates

	Number of Cointegrating Vectors	
Time Period	**Full System**	**EMS Subsystem**
Post-1973 Period	1	2
Pre-"Dollar Rescue" Period	0	1
Post-"Dollar Rescue" Period	1	2
Pre-EMS Period	1	1
Post-EMS Period	1	1
Pre-Peak Period	0	1
Post-Peak Period	3	1
Pre-Plaza Period	0	0
Post-Plaza Period	3	1
Pre-Louvre Period	0	0
Post-Louvre Period	0	0

Tables 3-24: Johansen Cointegration Test Results

The 5% critical values for the trace statistics of the null hypothesis that rank(Π) = r are listed below; the source is Osterwald-Lenum (1992). If a trace statistic is significant under the assumption that $\mu \neq 0$, it is marked with **.

Dimension of Π		H(r)
r	(n-r)	$\mu \neq 0$
4	4	47.410
3	5	68.524
2	6	94.155
1	7	124.243
0	8	155.999

Table 3. Johansen Cointegration Test Results for the Full System in the Post-1973 Period

	Trace Statistics
r	H(r)
4	32.3175
3	47.9406
2	68.6433
1	110.0213
0	160.2744**

Table 4. Johansen Cointegration Test Results for the Full System in the Pre-Dollar Rescue Period

	Trace Statistics
r	H(r)
4	31.0271
3	49.4256
2	69.2059
1	105.3181
0	155.8310

Table 5. Johansen Cointegration Test Results for the Full System in the Post-Dollar Rescue Period

	Trace Statistics
r	H(r)
4	31.4557
3	58.5751
2	88.2633
1	120.9527
0	164.0304**

Table 6. Johansen Cointegration Test Results for the Full System in the Pre-EMS Period

r	Trace Statistics H(r)
4	25.4597
3	42.0717
2	65.8132
1	104.4806
0	156.4098**

Table 7. Johansen Cointegration Test Results for the Full System in the Post-EMS Period

r	Trace Statistics H(r)
4	31.3092
3	54.8606
2	79.4686
1	112.3466
0	162.6838 **

Table 8. Johansen Cointegration Test Results for the Full System in the Pre-Peak Period

r	Trace Statistics H(r)
4	23.2316
3	40.5152
2	58.5681
1	90.7833
0	137.8266

Table 9. Johansen Cointegration Test Results for the Full System in the Post-Peak Period

r	Trace Statistics H(r)
4	44.2406
3	68.5852
2	98.0516 **
1	142.3415 **
0	267.1033 **

Table 10. Johansen Cointegration Test Results for the Full System in the Pre-Plaza Period

r	Trace Statistics H(r)
4	24.1218
3	40.5794
2	60.4225
1	91.0500
0	127.0183

Table 11. Johansen Cointegration Test Results for the Full System in the Post-Plaza Period

r	Trace Statistics H(r)
4	42.2340
3	64.5921
2	95.3069 **
1	133.2467 **
0	179.5316 **

Table 12. Johansen Cointegration Test Results for the Full System in the Pre-Louvre Period

r	Trace Statistics H(r)
4	25.0944
3	39.9255
2	59.9189
1	90.8637
0	128.4835

Table 13. Johansen Cointegration Test Results for the Full System in the Post-Louvre Period

r	Trace Statistics H(r)
4	31.8432
3	49.6656
2	77.4124
1	110.6171
0	150.850

Table 14. Johansen Cointegration Test Results for the EMS Subsystem in the Post-1973 Period

r	Trace Statistics H(r)
3	1.6127
2	14.8994
1	32.5348 **
0	63.8383 **

Table 15. Johansen Cointegration Test Results for the EMS Subsystem in the Pre-Dollar Rescue Period

r	Trace Statistics H(r)
3	1.1814
2	4.8994
1	16.3359
0	48.6840 **

Table 16. Johansen Cointegration Test Results for the EMS Subsystem in the Post-Dollar Rescue Period

r	Trace Statistics H(r)
3	1.7818
2	12.8313
1	29.7344 **
0	58.5574 **

Table 17. Johansen Cointegration Test Results for the EMS Subsystem in the Pre-EMS Period

r	Trace Statistics H(r)
3	2.2075
2	6.3416
1	18.1843
0	54.9489 **

Table 18. Johansen Cointegration Test Results for the EMS Subsystem in the Post-EMS Period

r	Trace Statistics H(r)
3	2.2459
2	15.7156 **
1	36.5782 **
0	71.0912 **

Table 19. Johansen Cointegration Test Results for the EMS Subsystem in the Pre-Peak Period

r	Trace Statistics H(r)
3	0.4921
2	8.5004
1	26.7178
0	50.7560 **

Table 20. Johansen Cointegration Test Results for the EMS Subsystem in the Post-Peak Period

r	Trace Statistics H(r)
3	5.5125
2	14.3179
1	30.6567**
0	69.0913 **

Table 21. Johansen Cointegration Test Results for the EMS Subsystem in the Pre-Plaza Period

r	Trace Statistics H(r)
3	0.0001
2	8.0007
1	19.7551
0	45.2917

Table 22. Johansen Cointegration Test Results for the EMS Subsystem in the Post-Plaza Period

r	Trace Statistics H(r)
3	2.9823
2	10.8225
1	25.8553
0	51.5630 **

Table 23. Johansen Cointegration Test Results for the EMS Subsystem in the Pre-Louvre Period

r	Trace Statistics H(r)
3	1.1206
2	10.4934
1	22.0338
0	46.7566

Table 24. Johansen Cointegration Test Results for the EMS Subsystem in the Post-Louvre Period

r	Trace Statistics H(r)
3	1.3289
2	7.7759
1	20.1681
0	39.7472

Table 25.
Quintos Cointegration Test Results for the Full System in the Post-1973 Period

Breakpoint	q	q_1	q_2	LR Statistic
"Dollar Rescue"	1	0	1	$LR^{\#} = 48.51$ *
EMS	1	1	1	---
Peak	1	0	3	$LR_1^{*} = 11515$ *
Plaza	1	0	3	$LR_1^{*} = 13014$ *
Louvre	1	0	0	$LR^{\#} = 76.27$ *

Note: The LR statistics that are significant at the 5% level are labeled with *.

Table 26.
Quintos Cointegration Test Results for the EMS Subsystem in the Post-1973 Period

Breakpoint	q	q_1	q_2	LR Statistic
"Dollar Rescue"	2	1	2	$LR^{\#} = 11.71$ *
EMS	2	1	1	$LR^{\#} = 27.80$ *
Peak	2	1	1	$LR^{\#} = 34.47$ *
Plaza	2	0	1	$LR^{\#} = 52.07$ *
Louvre	2	0	0	$LR^{\#} = 67.65$ *

Note: The LR statistics that are significant at the 5% level are labeled with *.

Table 27.
Quintos Cointegration Test Results for the Full System in the Defined Subperiods

Subperiod	q	q_1	q_2	LR Statistic
"Dollar Rescue"				
Start-EMS	1	0	1	$LR^{\#}$ = 48.51 *
Start-Peak	0	0	0	---
Start-Plaza	0	0	0	---
EMS				
Start-Peak	0	1	0	LR = 54.06 *
Start-Plaza	0	1	0	LR = 54.06 *
"DR"-Peak	0	1	0	LR = 55.94 *
"DR"-Plaza	0	1	0	LR = 55.94 *
Peak				
Start-Plaza	0	0	3	LR = 167.05 *
"DR"-Plaza	0	0	3	LR = 167.05 *
EMS-Plaza	0	0	3	LR = 167.05 *
Plaza				
Start-Louvre	0	0	2	LR = 124.25 *
"DR"-Louvre	0	0	2	LR = 124.25 *
EMS-Louvre	0	0	2	LR = 124.25 *
Peak-Louvre	1	3	2	LR = 154.64 *
Louvre				
"DR"-End	1	0	0	$LR^{\#}$ = 75.65 *
EMS-End	1	0	0	$LR^{\#}$ = 77.02 *
Peak-End	3	1	0	$LR^{\#}$ = 200.32 *
Plaza-End	3	2	0	$LR^{\#}$ = 154.65 *

Note: The LR statistics that are significant at the 5% level are labeled with *.

Table 28.
Quintos Cointegration Test Results for the EMS Subsystem in the Defined Subperiods

<u>Subperiod</u>	<u>q</u>	<u>q_1</u>	<u>q_2</u>	<u>LR Statistic</u>
"Dollar <u>Rescue"</u>				
Start-EMS	1	1	2	LR = 27.57 *
Start-Peak	1	1	0	LR = 31.24 *
Start-Plaza	0	1	0	LR = 31.33 *
<u>EMS</u>				
Start-Peak	1	1	0	$LR^{\#}$ = 19.10 *
Start-Plaza	0	1	0	LR = 14.92 *
"DR"-Peak	0	2	0	LR = 60.83 *
"DR"-Plaza	0	2	0	LR = 60.83 *
<u>Peak</u>				
Start-Plaza	0	1	1	LR = 65.86 *
"DR"-Plaza	0	0	1	LR = 19.14 *
EMS-Plaza	0	0	1	LR = 19.14 *
<u>Plaza</u>				
Start-Louvre	0	0	0	---
"DR"-Louvre				
EMS-Louvre	0	0	0	---
Peak-Louvre	0	0	0	---
	1	1	0	$LR^{\#}$ = 22.93 *
<u>Louvre</u>				
"DR"-End				
EMS-End	2	0	0	$LR^{\#}$ = 63.03 *
Peak-End	1	0	0	$LR^{\#}$ = 41.05 *
Plaza-End	1	1	0	$LR^{\#}$ = 19.28 *
	1	0	0	$LR^{\#}$ = 42.20 *

<u>Note:</u> The LR statistics that are significant at the 5% level are labeled with *.

Figure 1.
Daily Log Spot BP/$ Exchange Rate
1974-1992

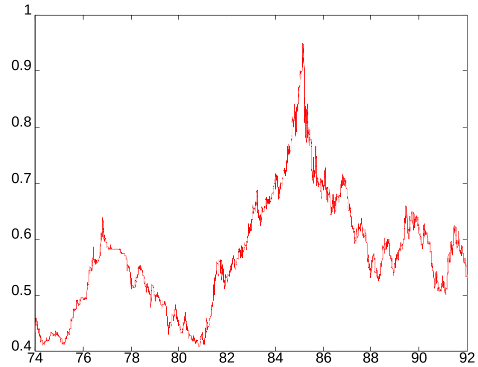

Figure 2.
Daily Log Spot DM/$ Exchange Rate
1974-1992

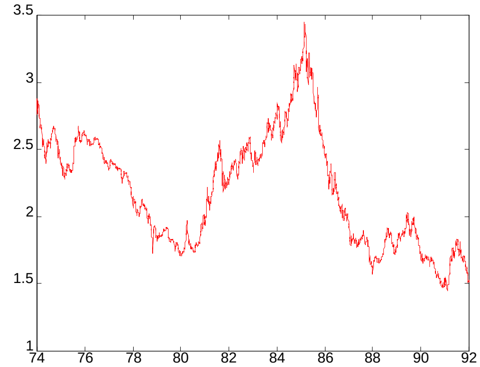

Figure 3.
Daily Log Spot JY/$ Exchange Rate
1974-1992

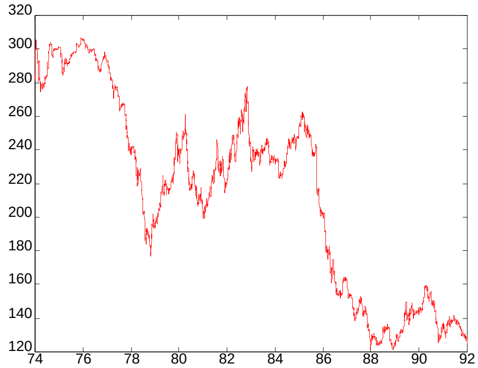

Figure 4.
Daily Spot FR/$ Exchange Rate
1974-1992

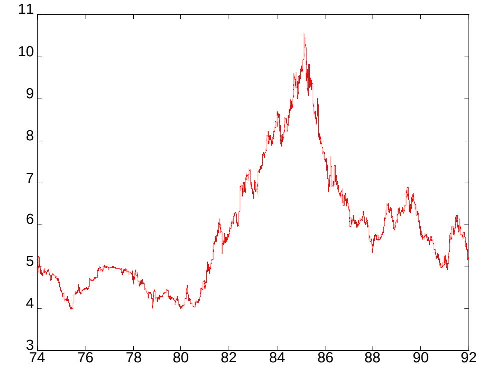

Figure 5.
Daily Spot NG/$ Exchange Rate
1974-1992

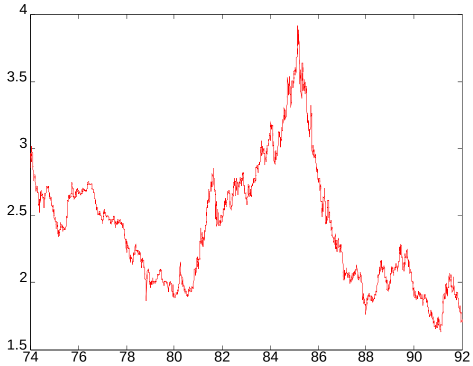

Figure 6.
Daily Log Spot LI/$ Exchange Rate
1974-1992

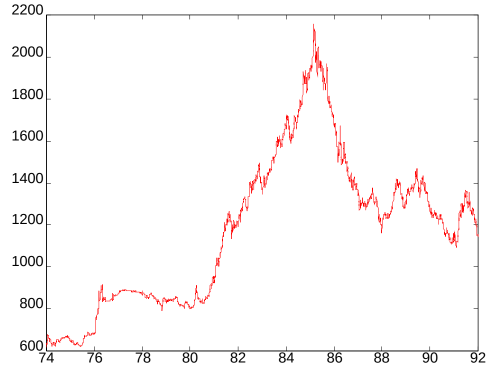

Figure 7.
Daily Log Spot SF/$ Exchange Rate
1974-1992

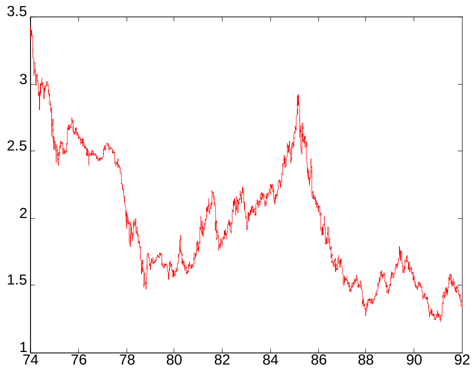

Figure 8.
Daily Log Spot CD/$ Exchange Rate
1974-1992

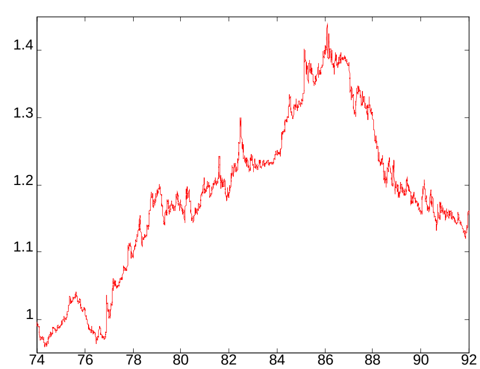

Figure 9. Timeline of Proposed Structural Breakpoints