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The Mussa Puzzle: A Generalization

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JEL Classi.cation: E42, E52, E65, F31, F33, F36

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Abstract

One of the most compelling pieces of evidence for monetary non-neutrality is the Mussa puzzle, in which the break in the monetary regime when the Bretton Woods System broke down increased the volatility of not only the nominal exchange rate but the real exchange rate. Using data covering thirty-one European countries from 1954 to 2019, I find that the Mussa puzzle is generalizable: any break in a monetary regime that changes the volatility of the nominal exchange rate also changes the volatility of the real exchange rate. This provides further evidence of monetary non-neutrality.

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1 Introduction

Nakamura and Steinsson (2018) write: "What is the most convincing evidence for monetary nonneutrality? When we ask prominent macroeconomists this question, the three most common answers have been: the evidence presented in Friedman and Schwartz (1963) regarding the role of monetary policy in the severity of the Great Depression; the Volcker disinflation of the early 1980s and accompanying twin recession; and the sharp break in the volatility of the US real exchange rate accompanying the breakdown of the Bretton Woods system of fixed exchange rates in 1973" (69–70). Primarily using bilateral time series on the United States and thirteen advanced countries for the period 1957-84, Mussa (1986) documents what is now referred to as the Mussa puzzle: the 1973 breakdown of the Bretton Woods System (BWS) increased the volatility of not only the nominal US-dollar exchange rate but the real US-dollar exchange rate which implies monetary non-neutrality. This result looks like a puzzle, as a break in a monetary regime should not affect any real variables in a world of monetary neutrality. In such a world, nominal shocks would affect the nominal exchange rate but not the real exchange rate, as such shocks would change the price level proportionately to the change in the nominal exchange rate. Mussa takes advantage of a natural experiment, using a discontinuity-based identification method in which the identifying assumption is that factors other than the monetary regime affecting the real exchange rate did not change discontinuously when the BWS broke down. Mussa reaches two conclusions from his empirical finding. First, the monetary regime is relevant to the real exchange rate because of price stickiness; the volatility of nominal exchange rate would not affect the volatility of the real exchange rate if prices were flexible and free to adjust. Second, theoretical models with price stickiness seem more relevant to macroeconomic theory than models without nominal rigidities to explain the observed empirical finding. Both conclusions have been recently corroborated by Paul Krugman, who intuits that Mussa's finding is not unique: a corresponding natural experiment in Europe appears to have generate a similar pattern.[1]

I follow Krugman's intuition by using data covering thirty-one European countries from 1957 to 2019, based on which I generalize the Mussa puzzle with the finding that a break in the monetary regime that changes the volatility of the nominal exchange rate also changes the volatility of the real exchange rate. I identify breaks in the monetary regime using two approaches: a narrative approach and an econometric approach. The narrative approach is based on several historical sources, whereas the econometric approach is based on two structural-break tests: the test developed by Lavielle (1999) and Lavielle and Moulines (2000) (L&M) and the test developed by Kokoszka and Leipus (1998, 1999, 2000) (K&L). Figure 1 and 2 take two countries as illustrative examples of my findings: Switzerland presents one monetary-regime break (the breakdown of the BWS); Italy presents four monetary-regime breaks (the exit

[1] **Krugman, Paul.** 2012. "Currencies, Prices, and Mike Mussa (A Bit Wonkish)." *New York Times.* January 18. https://krugman.blogs.nytimes.com/2012/01/18/currencies-prices-and-mike-mussa-a-bit-wonkish;
Krugman, Paul. 2011. "Exchange Rates and Price Stickiness (Wonkish)." *New York Times.* February 5. https://krugman.blogs.nytimes.com/2011/02/05/exchange-rates-and-price-stickiness-wonkish.

from the *Snake* and three additional breaks related to its adherence to the European Exchange Rate Mechanism [ERM]).[2] In the case of Switzerland, I reinforce the result found by Mussa (1986), and in the case of Italy I find additional monetary-regime breaks that changed the volatility of not only the nominal exchange rate but the real exchange rate. I present my results in table 1. I am able to provide evidence for monetary non-neutrality for several other European countries as well—namely, Bulgaria, Finland, France, Greece, Ireland, Latvia, Lithuania, Malta, Norway, Portugal, the Republic of Slovenia, Spain, Sweden, and the United Kingdom. What emerges from my work is that the Mussa puzzle is not a peculiar fact about exchange rates when the BWS broke down, but a more general fact about exchange rates at monetary-regime breaks: for fifteen monetary-regime breaks, other than the breakdown of the BWS, there were structural breaks in the volatility of the nominal exchange rate and real exchange rate.

[2]The ERM, a multilateral parity grid of exchange rates, was established in March 1979 in the context of the European Monetary System. It was the second attempt to create a multilateral parity grid of exchange rates in Europe, after the failure of the so-called *Snake*, which was established in April 1972.

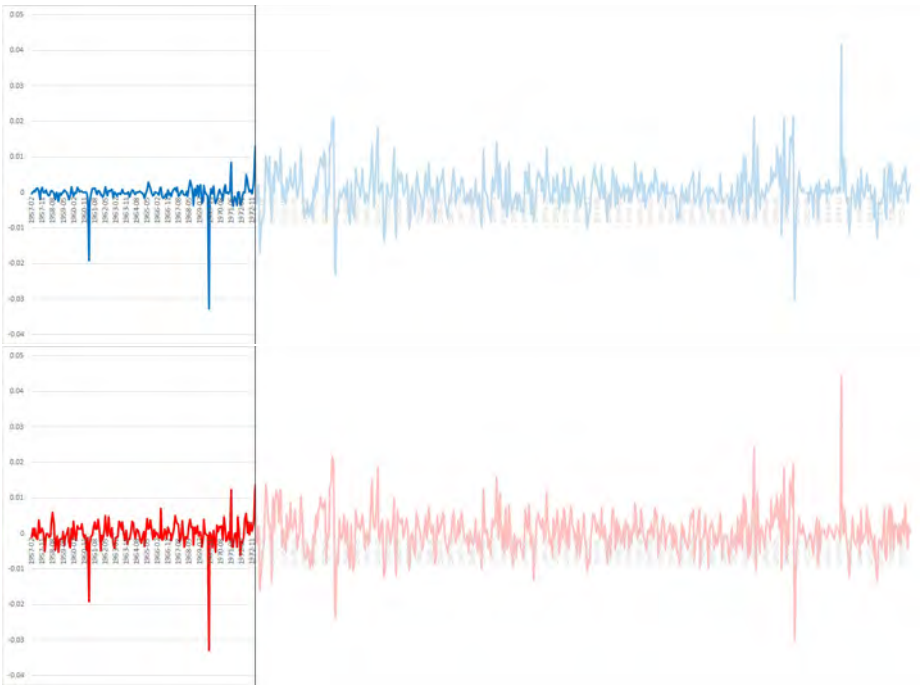

Figure 1: Switzerland (Foreign Country) and Germany (Home Country)

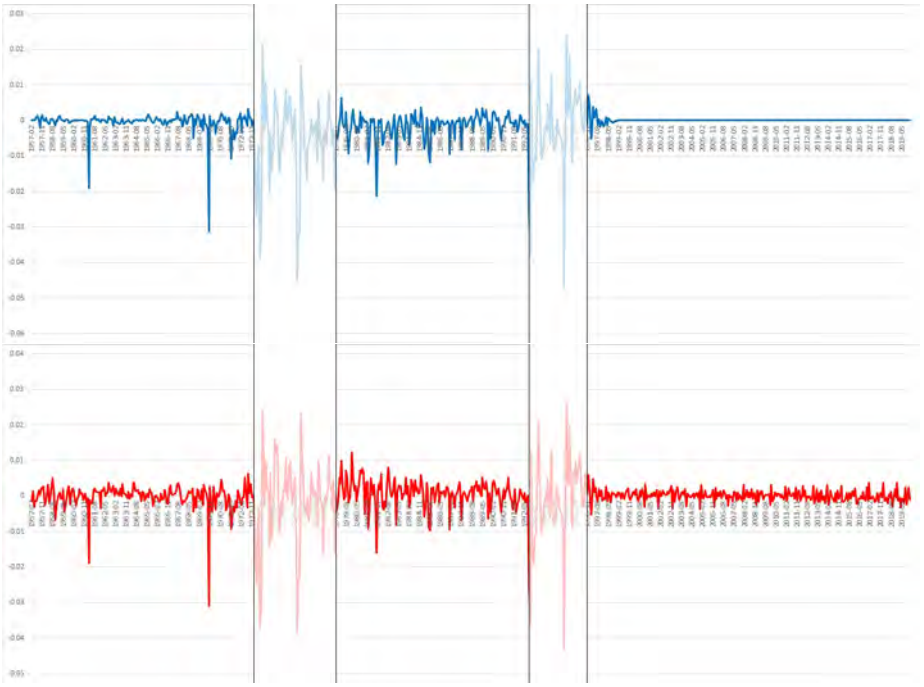

Figure 2: Italy (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches. I shade the periods with floating exchange rate regimes.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

2 Mussa Puzzle in Europe

2.1 Data

I choose Europe as a natural experiment for additional evidence of the Mussa puzzle for two reasons. First, Europe encompasses more countries than those analyzed in Mussa (1986); I take into account the twenty-seven member countries of the European Union plus Iceland, Norway, Switzerland, and the United Kingdom.[3] Second, European countries present a multiplicity of monetary regimes and many regime breaks. My data consist of monthly time series on nominal and real exchange rates from January 1957 to December 2019.[4] In my analysis of the exchange rates, the home country is Germany (West Germany before October 1990) and the foreign country is each of the other thirty European countries; the deutschmark is therefore the reference currency. I take this approach for two reasons. First, the choice of the deutschmark as reference currency permits me to take into account monetary-regime breaks other than the end of the BWS. If, by contrast, I considered the United States as the home country and the US dollar as the reference currency, I would only be able to confirm the empirical finding of Mussa, as no monetary-regime break has happened between the United States and, for example, Italy since the end of the BWS. Second, Germany represents the benchmark economy in Europe, which has led to several policy decisions by the other European countries.

I downloaded monthly time-series data on nominal exchange rates from the Exchange Rates Portal of the Bank of Italy, where the series were obtained by averaging the daily nominal exchange rates. I obtained the nominal exchange rate time series for each European country by combining the US-dollar/deutschmark time series and the US-dollar/euro time series after December 2001, at which time 1 euro was worth 1.95583 deutschmark, with the various US-dollar/foreign-currency time series. If a currency was renominated—for example the French franc in January 1960—I normalized the series in order to remove the ensuing jump. Following Mussa (1986), I use the consumer-price-index-based real exchange rate, to get which I construct the real-exchange-rate monthly time series using the nominal-exchange-rate monthly time series and the consumer price indexes from the International Financial Statistics of the International Monetary Fund.

2.2 Narrative Approach

My primary historical source for the narrative approach is James (2014). However, given that James covers the history of the European Monetary Union only up to the start of physical circulation of euro notes and coins in January 2002, I use additional

[3] The twenty-seven member countries of the European Union are Austria, Belgium, Bulgaria, the Republic of Croatia, Cyprus, the Czech Republic, Denmark, the Republic of Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, the Republic of Poland, Portugal, Romania, the Slovak Republic, the Republic of Slovenia, Spain, and Sweden.

[4] Complete data for all the considered European countries are not available. The list of time windows for each country can be found in table 2 in the appendix.

documents to extend my data to December 2019.[5]
The narrative approach yields results reported in the second column of table 1: for each European country, I identify a set of dates that correspond to monetary-regime breaks. I follow Nakamura and Steinsson (2018) in considering the 10 percent devaluation of the US dollar on February 12, 1973, as the breakdown of the BWS. I define a monetary-regime break in general as a formal or informal event that changes the nominal-exchange-rate regime between the home country (Germany) and the foreign country (each of the other European countries) from a fixed (or pegged) exchange rate regime to a floating exchange rate regime or vice versa. This definition of a monetary-regime break has two implications. First, the set of dates that correspond to monetary-regime breaks is empty for some European countries because the definition does not include movements in the nominal exchange rate (revaluations/devaluations or appreciations/depreciations). Second, the introduction of the euro was not a monetary-regime break, as the volatility of the nominal exchange rate is not affected by a change from a fixed exchange rate regime to a currency union.

2.3 Econometric Approach

I apply two tests to empirically identify structural breaks in the volatility of the nominal exchange rate and real exchange rate series: the L&M test and the K&L test. Their application to this research question is novel, as both tests come from the financial econometrics literature and aim to identify structural breaks in the volatility of asset returns. The L&M test is an extension of the and Bai and Perron (1998) test for weakly and strongly dependent processes. It is used to simultaneously detect structural breaks in the volatility of a time series when the number of structural breaks is unknown. The L&M test does not allow for statistical inference. The K&L test is a cumulative sum (CUSUM) test: it was initially developed to detect a single structural break, but it can be used to detect multiple structural breaks if it is sequentially implemented, according to Andreou and Ghysels (2002).[6] The K&L test allows for statistical inference.
Formally, consider this definition of a real exchange rate:

$$R_t \equiv E_t \frac{P_t^*}{P_t} \tag{1}$$

R_t is the consumer-price-index-based real exchange rate (defined as the price of the foreign-country commodity basket in terms of the home-country commodity basket), E_t is the nominal exchange rate (defined as the amount of home currency per unit of foreign currency), and $\frac{P_t^*}{P_t}$ is the ratio of the foreign price level to the domestic price

[5] Table 3 in the appendix reports the historical source for each European country. All the documents are available on request from the author.

[6] My sequential procedure works as follows. Starting from the whole sample, I run the K&L test. If a structural break point is estimated, I divide the sample into two sub-samples at the estimated structural break point. I perform the K&L test for each sub-sample, and I divide the sub-sample at the estimated structural break point (if any) into nested sub-samples and do the same analysis. I repeat this step until all the monetary-regime breaks from the narrative approach are empirically identified or all the sub-samples fail to reject the null hypothesis of no structural break.

level. Taking the natural logarithm of both sides, we find the following:

$$r_t = e_t + p_t^* - p_t \tag{2}$$

r_t is the natural logarithm of the real exchange rate, e_t is the natural logarithm of the nominal exchange rate, p_t^* is the natural logarithm of the foreign price level, and p_t is the natural logarithm of the domestic price level. An increase in r_t is equivalent to an increase in the real value of foreign goods in terms of domestic goods, and it can be driven by an increase in e_t, an increase in $p_t^* - p_t$, or both. From equation (2), we can derive the following relationships:

$$\Delta r_t = \Delta e_t + \Delta p_t^* - \Delta p_t = \Delta e_t + \pi_t^* - \pi_t \tag{3}$$

Here $\Delta x_t \equiv x_t - x_{t-1}$, and the second equality follows from the definition of the inflation rate as $\pi_t = \ln(P_t) - \ln(P_{t-1})$. This is the crucial equation since it establishes a relation between the volatility of the real exchange rate, the volatility of the nominal exchange rate, and the volatility of $\pi_t^* - \pi_t$—that is, the difference between the inflation rate in the foreign country and the inflation rate in the domestic country. In the context of the breakdown of the BWS, Mussa (1986) points out that the break in the monetary regime in 1973 (from fixed to floating nominal exchange rates) simultaneously increased the volatility of Δe_t and Δr_t, leaving unchanged the volatility of $\pi_t^* - \pi_t$.

Denote $X_t = \Delta e_t$ (or $X_t = \Delta r_t$), $t = 1, 2, 3, ..., T$. Assume that the unknown number of segments K in the time series is upper bounded by a known finite $\bar{K}$. Lavielle (1999) and Lavielle and Moulines (2000) propose to estimate the configuration of structural breaks τ and the number of segments K by minimizing the penalized-contrast function, as follows:

$$(\hat{\tau}_T, \hat{K}_T) = \arg \min_{1 \le K \le \bar{K}} \inf_{\tau \in \mathcal{T}_K} \left\{ \frac{1}{T} \sum_{k=1}^{K} \left(\frac{||\mathbf{X}_k||^2}{\sigma_k^2} + T_k \ln \sigma_k^2 \right) + \beta_T K \right\} \tag{4}$$

$\mathbf{X}_k$ is the vector of observations that belong to segment k in the configuration $\tau = (\tau_k, 1 \le k \le K-1)$, T_k is the length of $\mathbf{X}_k$, σ_k^2 is the variance of X_t in segment k, and $\beta_T K$ is the penalization term. In my analysis, I pose $\bar{K} = 6$, which implies a maximum of five structural breaks, and I choose β_T following Lavielle (1999).[7]

Denote $Y_t = |\Delta e_t|$ (or $Y_t = |\Delta r_t|$), $t = 1, 2, 3, ..., T$. The test statistics by Kokoszka and Leipus (1998, 1999, 2000) is as follows:

$$U_T(k) = T^{-1/2} \left[\sum_{j=1}^{k} Y_j - \frac{k}{T} \sum_{j=1}^{T} Y_j \right] \text{ with } 0 < k < T \tag{5}$$

The CUSUM estimator $\hat{k}$ of a structural break point is defined as follows:

$$\hat{k} = \min \left\{ k : |U_T(k)| = \max_{1 \le j \le T} |U_t(j)| \right\} \tag{6}$$

[7] Lavielle (1999, p. 81) suggests choosing such a parameter, following not theoretical considerations but practical ones, in order to obtain a resolution level—that is, a number of breaks—that seems satisfactory. Then, I set: $\beta_T = 0.5$ for Bulgaria and Lithuania; $\beta_T = 0.25$ for Finland, Latvia, Sweden, the Slovak Republic, the Republic of Slovenia, and the United Kingdom; $\beta_T = 0.10$ for Cyprus, Greece, Portugal, Spain, and Switzerland; $\beta_T = 0.05$ for France, Ireland, Italy, and Norway; $\beta_T = 0.025$ for Malta.

Under the null hypothesis of no structural break,

$$\frac{U_T(k)}{\hat{\sigma}_{HAC}} \xrightarrow{D[0,1]} W^0(k), \tag{7}$$

where $\hat{\sigma}^2_{HAC}$ is the HAC estimator of the long-run variance and $W^0(k)$ is a Brownian bridge. Consequently, statistical inference is possible and I can reject the null hypothesis of no structural break for a given significance level.[8] For the HAC estimator of the long-run variance I employ the following equation:

$$\hat{\sigma}^2_{HAC} = \sum_{|j|\leq q} \omega_j(q)\hat{\gamma}_j \tag{8}$$

$\hat{\gamma}_j$ are the sample covariances

$$\hat{\gamma}_j = \frac{1}{T}\sum_{i=1}^{T-|j|}(Y_i - \bar{Y})(Y_{i+|j|} - \bar{Y}), |j| < T,$$

$\omega_j(q)$ are the Bartlett weights

$$\omega_j(q) = 1 - \frac{|j|}{q+1},$$

$\bar{Y} = T^{-1}\sum_{j=1}^{T} Y_j$ (sample mean), and q is the lag parameter, which is non-parametrically estimated following Newey and West (1994).

The econometric approach yields the results in the third and fourth columns of table 1, in which the structural breaks for the nominal exchange rate and the real exchange rate are respectively reported. For each European country with a non-empty set of monetary-regime breaks gleaned from the narrative approach, I run the L&M test and the K&L test.[9] In order to be consistent with my definition of monetary-regime break, which excludes the introduction of the euro, for the European countries in the euro area I run the two structural-break tests up to the month before the currency was irrevocably fixed to the euro.[10] I empirically identify a set of structural breaks in the volatility of the nominal exchange rate and real exchange rate series, and I report in table 1 the structural breaks due to the monetary-regime breaks identified with the narrative approach. The fact that a structural break in the volatility of the time series for the nominal (real) exchange rate N1 (R1) is due to a monetary-regime break M1 is implied by the consideration that M1 and N1 (R1) are reasonably close in time. For two reasons, the L&M test and the K&L test do not always identify the structural breaks in the volatility of the nominal exchange rate and real exchange rate series at the same dates: first, the specific structure of the two structural-break tests varies and, second, their sensitiveness to observations that significantly depart from the others varies.

[8] I take the critical values for the Brownian bridge from table 9 in Schumacher (1984).

[9] I preliminarily remove the outliers from the Δe_t series and the Δr_t series to properly apply the two structural-break tests. I define outliers as elements more than three local standard deviations away from the local mean within a forty-nine-month window that is centered about the current element and contains forty-eight neighboring months.

[10] I report the list of the last month for each European country in the euro area in table 2 in the appendix.

2.4 Results

Table 1 summarizes the narrative approach and the econometric approach for all European countries. The second column (Narrative Approach) reports the monetary-regime breaks that I identify with the narrative approach. The third column (NER Breaks) and the fourth column (RER Breaks) respectively report the structural breaks in volatility in the series for the nominal exchange rate and in the series for the real exchange rate that are due to the monetary-regime breaks identified with the narrative approach. The results from both tests for all the European countries considered in the econometric approach are reported, with the L&M test in the first row and the K&L test in the second row.

The crucial result in table 1 is that for every time that I find a structural break in the volatility of the time series of the nominal exchange rate due to a monetary-regime break identified with the narrative approach, there is a structural break in the volatility of the series for the real exchange rate. In other words, every break in the intersection between the set of monetary-regime breaks identified with the narrative approach and the set of structural breaks in the volatility of the nominal exchange rate series corresponds with a structural break in the volatility of the real exchange rate series. It is a generalization of the Mussa puzzle: not only can I confirm what Mussa (1986) finds about the breakdown of the BWS (see my results for Finland, Greece, Portugal, Spain, and Switzerland) but I can also supply evidence for monetary non-neutrality at the time of several other monetary-regime breaks (see my results for Bulgaria, France, Greece, Ireland, Italy, Latvia, Lithuania, Malta, Norway, Portugal, the Republic of Slovenia, Sweden, and the United Kingdom).[11]

The additional evidence is based on monetary-regime breaks, other than the breakdown of the BWS, that changed the volatility of not only the nominal exchange rate but the real exchange rate. I thus provide further and stronger evidence of monetary non-neutrality since my generalization is based on a longer period and a larger set of monetary-regime breaks than those in Mussa (1986).

[11] The figures for the Δe_t series and the Δr_t series for all the considered European countries are in the appendix. In the figures for Bulgaria, Finland, France, Greece, Ireland, Italy, Latvia, Lithuania, Malta, Norway, Portugal, the Republic of Slovenia, Spain, Sweden, Switzerland, and the United Kingdom, I report monetary-regime breaks that are identified with the narrative and econometric approaches.

Table 1: Identification of Monetary-Regime Breaks

Country	Narrative Approach	NER Breaks	RER Breaks
Austria	No Break *Pegged Exchange Rate Regime*		
Belgium	No Break *Pegged Exchange Rate Regime*		
Bulgaria	July 1 1997 *Currency Board*	7/1997 7/1997 (2.3029)	9/1997 9/1997 (2.2787)
Republic of Croatia	No Break *Floating Exchange Rate Regime*		
Cyprus	June 19 1992 *Pegged to the ECU*[a]	No Break	No Break
Czech Republic	No Break *Floating Exchange Rate Regime*		
Denmark	No Break *Pegged Exchange Rate Regime*		
Republic of Estonia	No Break *Pegged Exchange Rate Regime*		
Finland	February 12 1973 *BWS Breakdown*	6/1968 1/1973 (2.6784)	9/1969 1/1973 (2.3877)
	October 14 1996 *ERM Accession*[b]	No Break	No Break
France	January 19 1974 *Snake Exit*[b]	No Break	No Break
	May 9 1975 *Snake Re-accession*[b]	No Break	No Break
	March 15 1976 *Snake Exit*[b]	No Break	No Break
	November 20 1978 *ERM Agreement*[b]	10/1978 10/1978 (2.4653)	10/1978 10/1978 (1.3644)

Country	Narrative Approach	NER Breaks	RER Breaks
Greece	February 12 1973	2/1971	1/1971
	BWS Breakdown	12/1971 (2.4382)	1/1971 (2.2758)
	July 1 1985	1/1987	12/1985
	ERM Accession[b]	1/1986 (2.7023)	9/1983 (2.5669)
Hungary	No Break		
	Floating Exchange Rate Regime		
Iceland	No Break		
	Floating Exchange Rate Regime		
Ireland	November 20 1978	10/1978	4/1982
	ERM Agreement[b]	5/1979 (2.2932)	7/1982 (2.2858)
	August 2 1993	6/1993	7/1993
	ERM Loosening[b]	6/1993 (2.1496)	7/1993 (1.8648)
Italy	February 13 1973	1/1973	1/1973
	Snake Exit[b]	1/1973 (2.1881)	1/1973 (2.0665)
	November 20 1978	12/1977	7/1976
	ERM Agreement[b]	5/1978 (1.7733)	10/1978 (1.6067)
	September 17 1992	8/1992	8/1992
	ERM Exit[b]	8/1992 (1.8805)	8/1992 (1.5613)
	November 25 1996	7/1997	4/1997
	ERM Re-accession[b]	5/1996 (1.6551)	5/1996 (1.5241)
Latvia	January 1 2005	1/2005	7/2002
	Pegged to the Euro	4/2004 (2.5406)	8/2001 (2.4640)
Lithuania	February 2 2002	2/2002	2/2002
	Pegged to the Euro	2/2002 (2.9124)	2/2002 (2.9154)
Luxembourg	No Break		
	Pegged Exchange Rate Regime		
Malta	May 2 2005	5/2005	1/2003
	ERM II Accession[c]	4/2005 (1.7333)	1/2003 (1.3182)
Netherlands	No Break		
	Pegged Exchange Rate Regime		

Country	Narrative Approach	NER Breaks	RER Breaks
Norway	December 12 1978 *Snake Exit*[b]	5/1973 6/1977 (2.9799)	5/1973 8/1977 (2.2620)
Republic of Poland	No Break *Floating Exchange Rate Regime*		
Portugal	February 12 1973 *BWS Breakdown*	4/1971 1/1973 (2.5032)	8/1971 2/1973 (2.5666)
	November 10 1987 *ERM Accession*[b]	1/1987 1/1987 (2.3457)	1/1985 1/1985 (1.7268)
Romania	No Break *Floating Exchange Rate Regime*		
Slovak Republic	November 28 2005 *ERM II Accession*[c]	No Break	No Break
Republic of Slovenia	June 28 2004 *ERM II Accession*[c]	7/2004 7/2004 (1.8640)	7/1998 7/1998 (2.2618)
Spain	February 12 1973 *BWS Breakdown*	1/1973 1/1973 (1.9296)	5/1973 1/1973 (1.4893)
	May 13 1987 *ERM Accession*	No Break	No Break
Sweden	August 28 1977 *Snake Exit*[b]	4/1971 3/1977 (3.0495)	12/1970 11/1977 (2.7296)
Switzerland	February 12 1973 *BWS Breakdown*	4/1971 12/1972 (2.4919)	4/1971 12/1972 (2.1050)
United Kingdom	June 23 1972 *Snake Exit*[b]	4/1971 5/1972 (3.0648)	5/1972 6/1972 (2.9315)
	October 10 1990 *ERM Accession*[b]	No Break	No Break
	September 16 1992 *ERM Exit*[b]	No Break	No Break

Note: For each European country considered in the econometric approach, the results from the L&M test are in the first row and the results from the K&L test are in the second row. I report the value of the test statistics for the K&L test in square brackets; the 90%, 95%, and 99% (two-sided test) critical values are, respectively, 1.2238, 1.3582 and 1.6277. [a]The European Currency Unit (ECU) was a unit of account used in the ERM. [b]For more information on the *Snake* and the ERM, see footnote 2. [c]The ERM was replaced by the European Exchange Rate Mechanism II (ERM II) in January 1999 with the introduction of the euro.

3 Conclusion

This paper generalizes the Mussa puzzle—the finding that a monetary-regime break that changes the volatility of the nominal exchange rate also changes the volatility of the real exchange rate—and thus finds further and stronger evidence of monetary non-neutrality. In light of this result, there are three steps to take to move forward.

First, existing theoretical models on the Mussa puzzle are exclusively based on the seminal analysis of Mussa (1986). On one side, Monacelli (2004) agrees with the two conclusions by Mussa and proposes a model that is broadly consistent with Mussa's findings and combines nominal price rigidity and complete exchange rate pass-through. On the other side, Itskhoki and Mukhin (2019) propose a model of a segmented financial market—a particular type of financial friction—and argue that monetary non-neutrality arises from the financial-market segmentation and not the price stickiness, which is not necessary for the qualitative findings of the model. Consequently, a natural next step is to reconsider such models by taking into account not only the monetary-regime break at the breakdown of the BWS, but also the monetary-regime breaks I identified in table 1.

Second, an answer to the fundamental question arising from the two conclusions of Mussa (1986) remains essential: do prices adjust at the time of a monetary-regime break that modifies the volatility of the nominal exchange rate? The question has to be systematically investigated at the micro level: how do firms set prices immediately before and after a monetary-regime break that changes the volatility of the nominal exchange rate? A systematic empirical analysis, in the spirit of Cavallo, Neiman and Rigobon (2014), of one or more of the monetary-regime breaks that I identified in table 1, might shed some light on firms' pricing behavior at the time of a monetary-regime break and resolve the Mussa puzzle.

Finally, notice in table 1 that in some countries the monetary-regime breaks did not affect the volatility of the nominal exchange rate. This is the case for Cyprus, Finland, France, the Slovak Republic, Spain, and the United Kingdom. This empirical finding is the consequence of (1) the policy strategy of central banks in periods preceding the monetary-regime breaks (that is, Cyprus and Finland in the '90s; the Slovak Republic in the 2000s; and Spain in the '80s) and (2) a monetary regime that lasts for too short a period of time (that is, France's accession to and exit from the *Snake* and the UK's accession to and exit from the ERM). This empirical finding does not affect the main result of this paper, as my only interest here is in monetary-regime breaks that affected the volatility of the nominal exchange rate. However, my work could be extended to add data to the narrative approach for Cyprus, Finland, the Slovak Republic, and Spain in order to explain the absence of structural breaks in the volatility of nominal exchange rate series that results from the policy strategy of their central banks in periods preceding the monetary-regime breaks.

References

Andreou, Elena, and Eric Ghysels. 2002. "Detecting Multiple Breaks in Financial Market Volatility Dynamics." *Journal of Applied Econometrics*, 17(5): 579–600.

Andrews, Donald W. K. 1991. "Heteroskedasticity and Autocorrelation Consistent Covariance Matrix Estimation." *Econometrica*, 59(3): 817–858.

Bai, Jushan, and Pierre Perron. 1998. "Estimating and Testing Linear Models with Multiple Structural Changes." *Econometrica*, 66(1): 47–78.

Cavallo, Alberto, Brent Neiman, and Roberto Rigobon. 2014. "Currency Unions, Product Introductions, and the Real Exchange Rate." *The Quarterly Journal of Economics*, 129(2): 529–595.

Cavallo, Alberto, Brent Neiman, and Roberto Rigobon. 2015. "The Price Impact of Joining a Currency Union: Evidence from Latvia." *IMF Economic Review*, 63(2): 281–297.

Itskhoki, Oleg. 2020. "The Story of the Real Exchange Rate." *Working Paper*.

Itskhoki, Oleg, and Dmitry Mukhin. 2019. "Mussa Puzzle Redux." *Working Paper*.

James, Harold. 2014. *Making the European Monetary Union.* The Belknap Press of Harvard University Press.

Kokoszka, Piotr, and Remigijus Leipus. 1998. "Change-Point in the Mean of Dependent Observations." *Statistics & Probability Letters*, 40(4): 385–393.

Kokoszka, Piotr, and Remigijus Leipus. 1999. "Testing for Parameter Changes in ARCH Models." *Lithuanian Mathematical Journal*, 39(2): 182–195.

Kokoszka, Piotr, and Remigijus Leipus. 2000. "Change-Point Estimation in ARCH Models." *Bernoulli*, 6(3): 513–539.

Lavielle, Marc. 1999. "Detection of Multiple Changes in a Sequence of Dependent Variables." *Stochastic Processes and their Applications*, 83(1): 79–102.

Lavielle, Marc, and Eric Moulines. 2000. "Least-Squares Estimation of an Unknown Number of Shifts in a Time Series." *Journal of Time Series Analysis*, 21(1): 33–59.

Monacelli, Tommaso. 2004. "Into the Mussa Puzzle: Monetary Policy Regimes and the Real Exchange Rate in a Small Open Economy." *Journal of International Economics*, 62(1): 191–217.

Mussa, Michael. 1986. "Nominal Exchange Rate Regimes and the Behavior of Real Exchange Rates: Evidence and Implications." *Carnegie-Rochester Conference Series on Public Policy*, 25: 117–214.

Nakamura, Emi, and Jón Steinsson. 2018. "Identification in Macroeconomics." *Journal of Economic Perspectives*, 32(3): 59–86.

Newey, Whitney K., and Kenneth D. West. 1987. "A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix." *Econometrica*, 55(3): 703–708.

Newey, Whitney K., and Kenneth D. West. 1994. "Automatic Lag Selection in Covariance Matrix Estimation." *The Review of Economic Studies*, 61(4): 631–653.

Schumacher, Martin. 1984. "Two-Sample Tests of Cramér–von Mises- and Kolmogorov–Smirnov-Type for Randomly Censored Data." *International Statistical Review / Revue Internationale de Statistique*, 52(3): 263–281.

Appendix

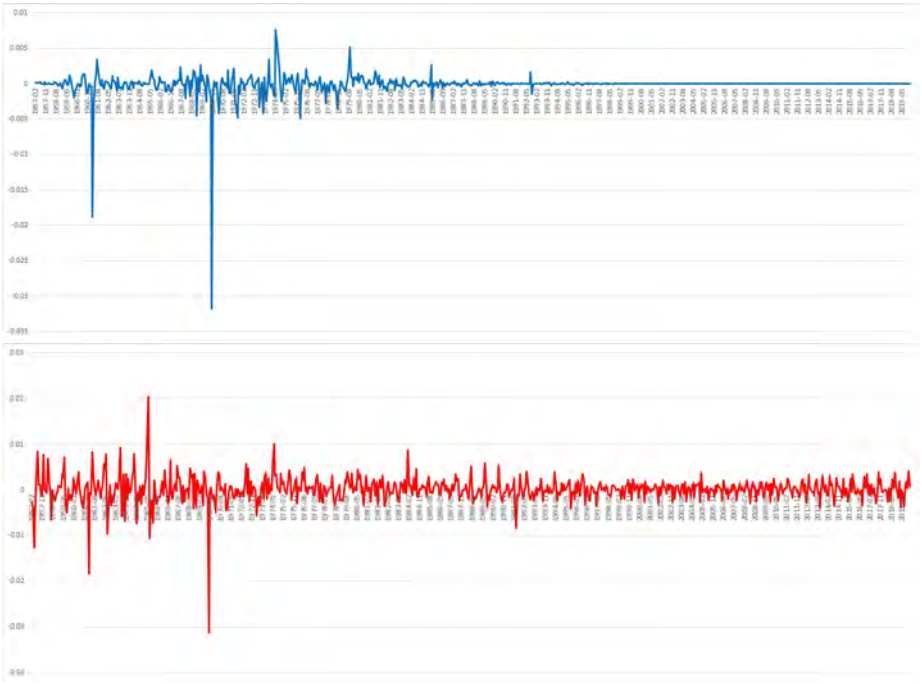

Figure 3: Austria (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

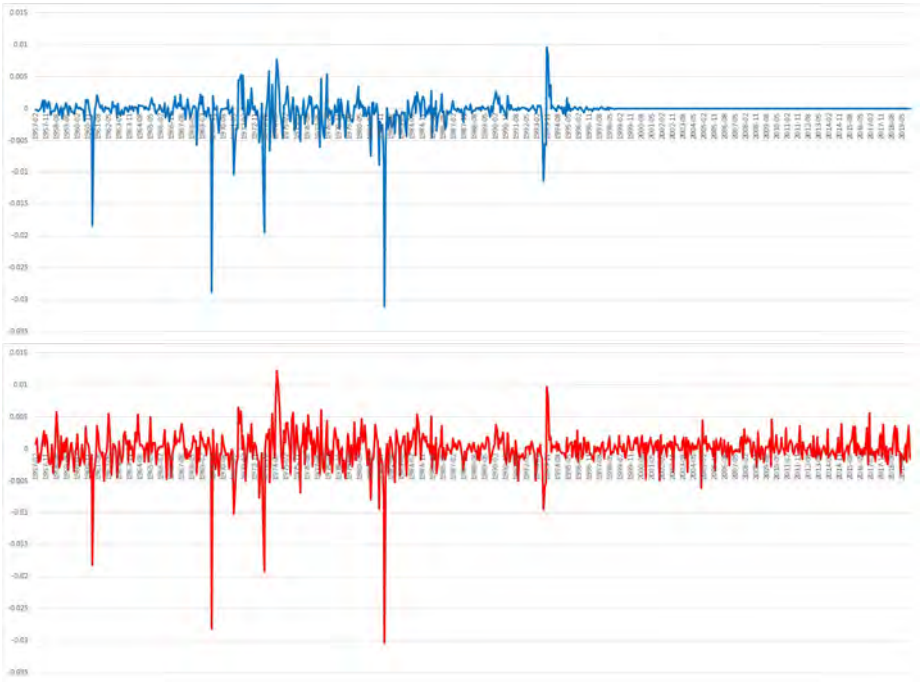

Figure 4: Belgium (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

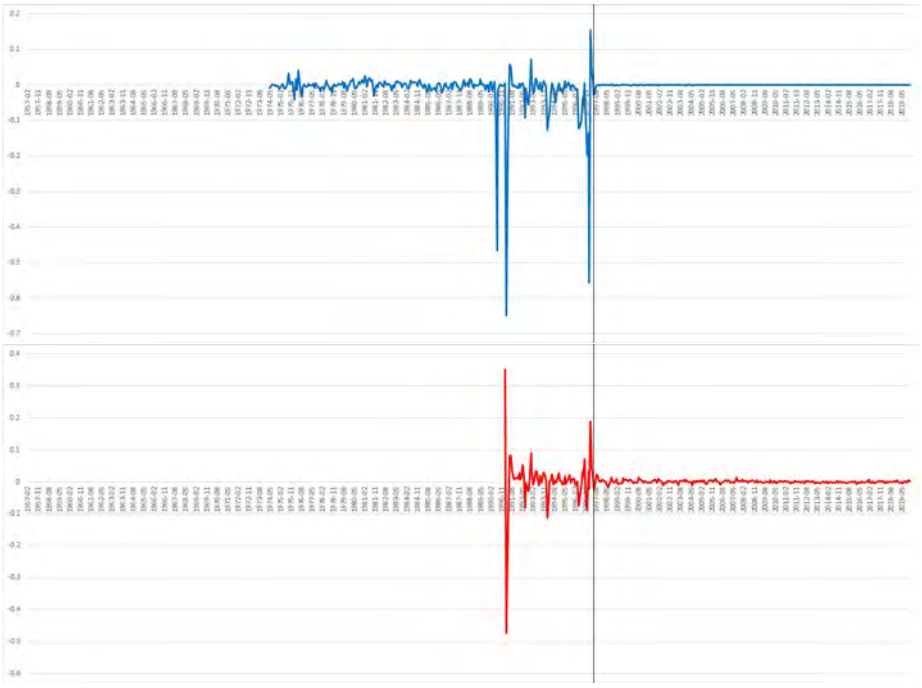

Figure 5: Bulgaria (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

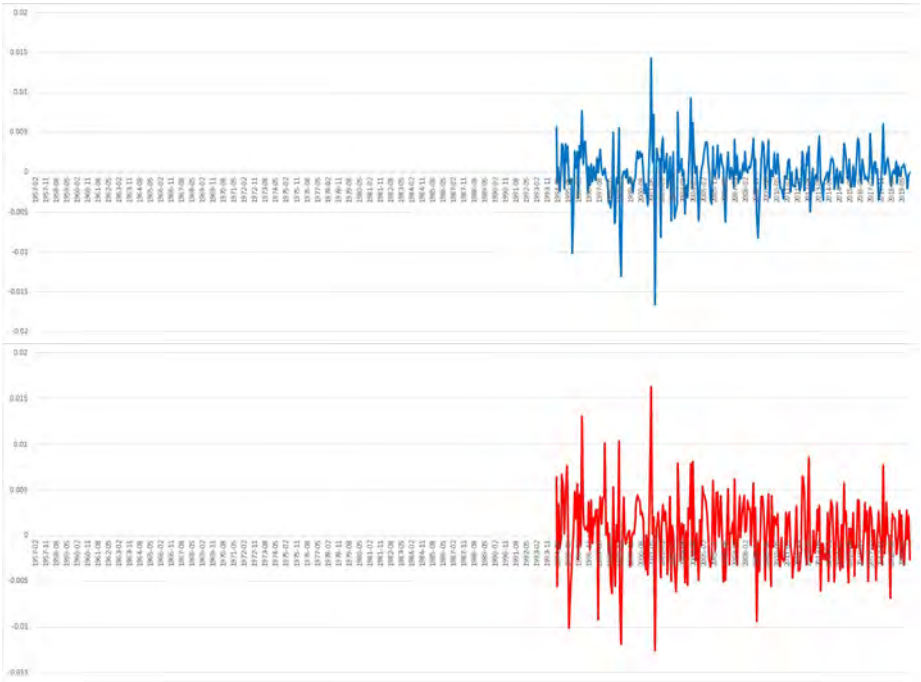

Figure 6: Republic of Croatia (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

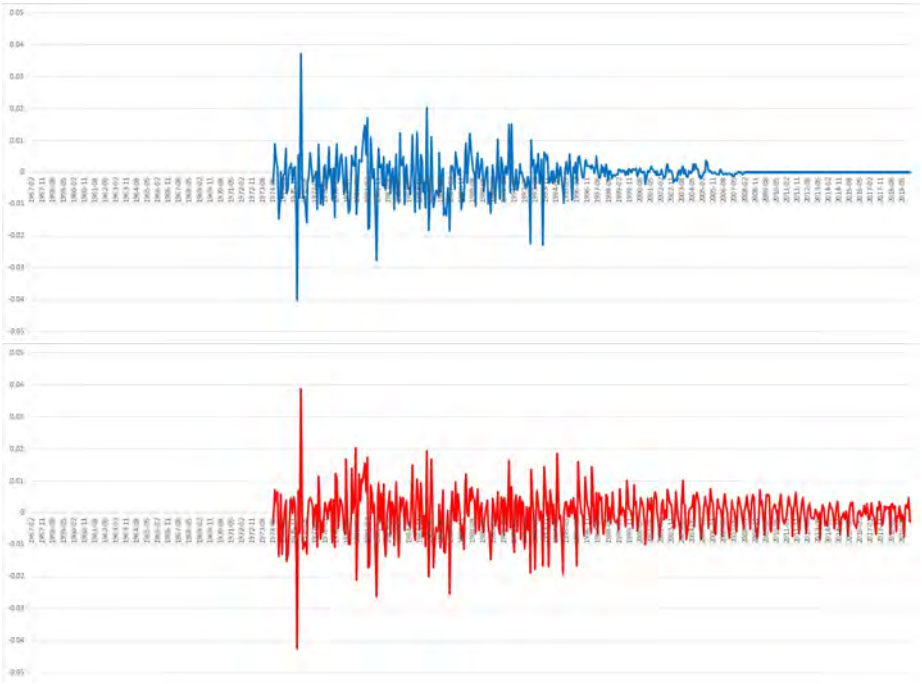

Figure 7: Cyprus (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

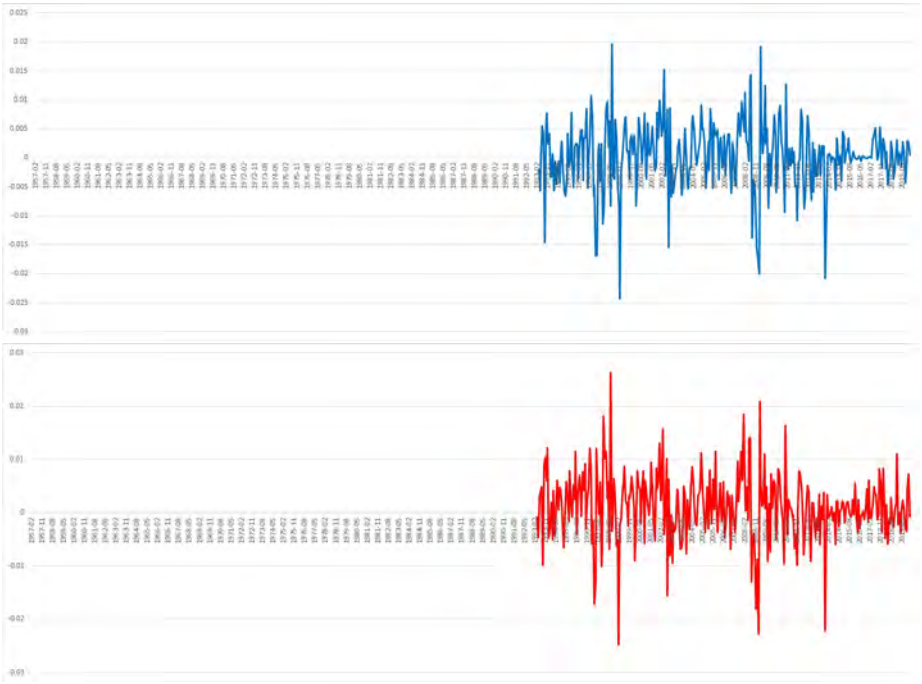

Figure 8: Czech Republic (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

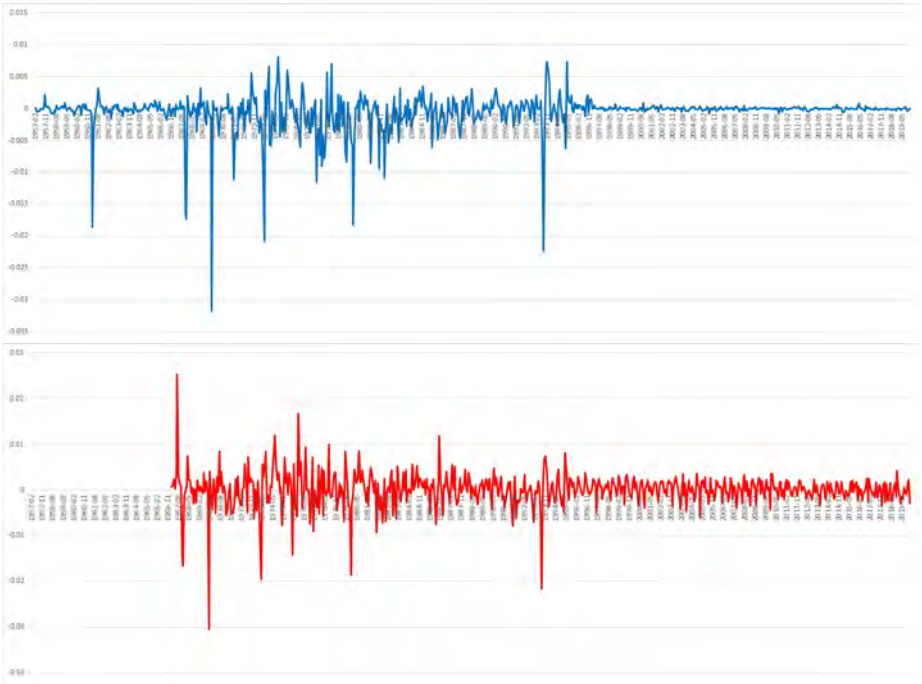

Figure 9: Denmark (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

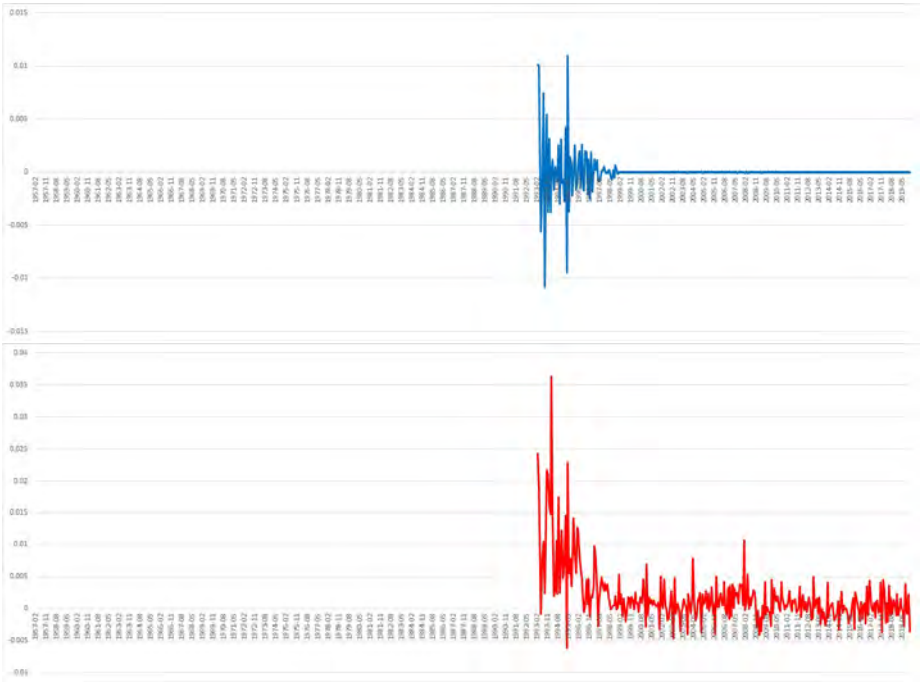

Figure 10: Republic of Estonia (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

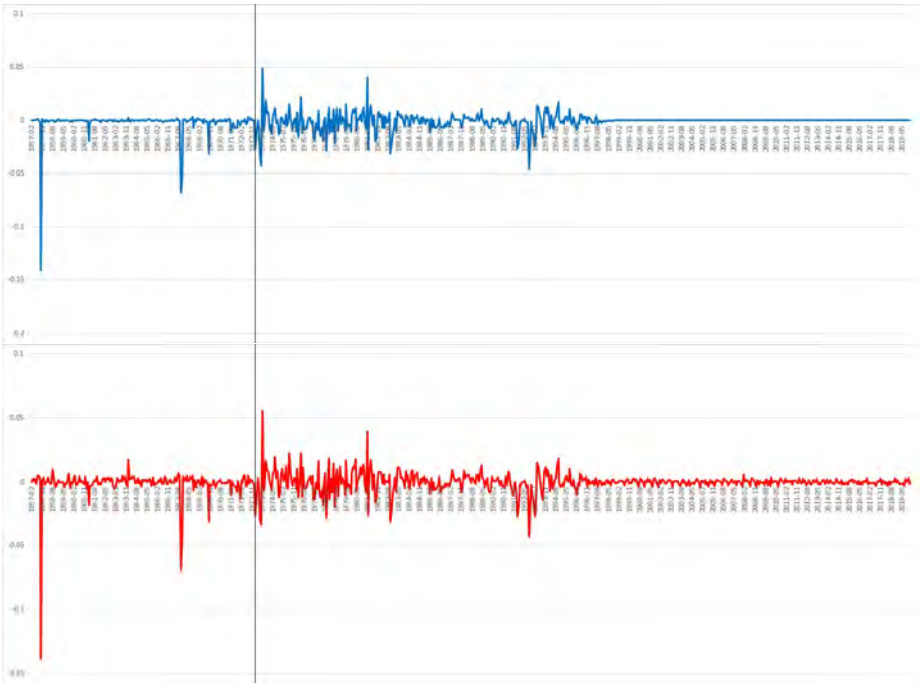

Figure 11: Finland (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

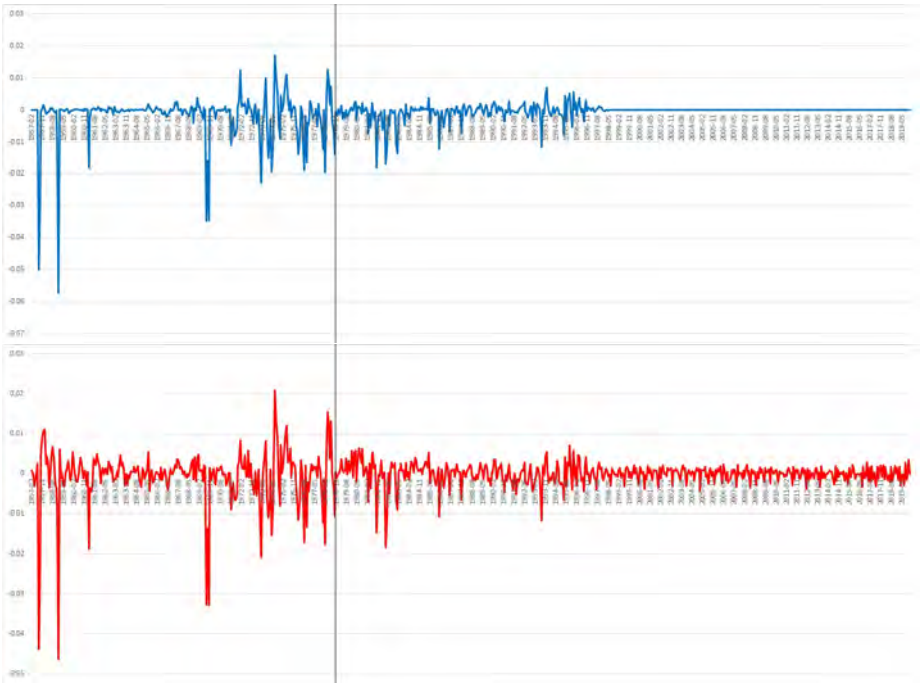

Figure 12: France (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

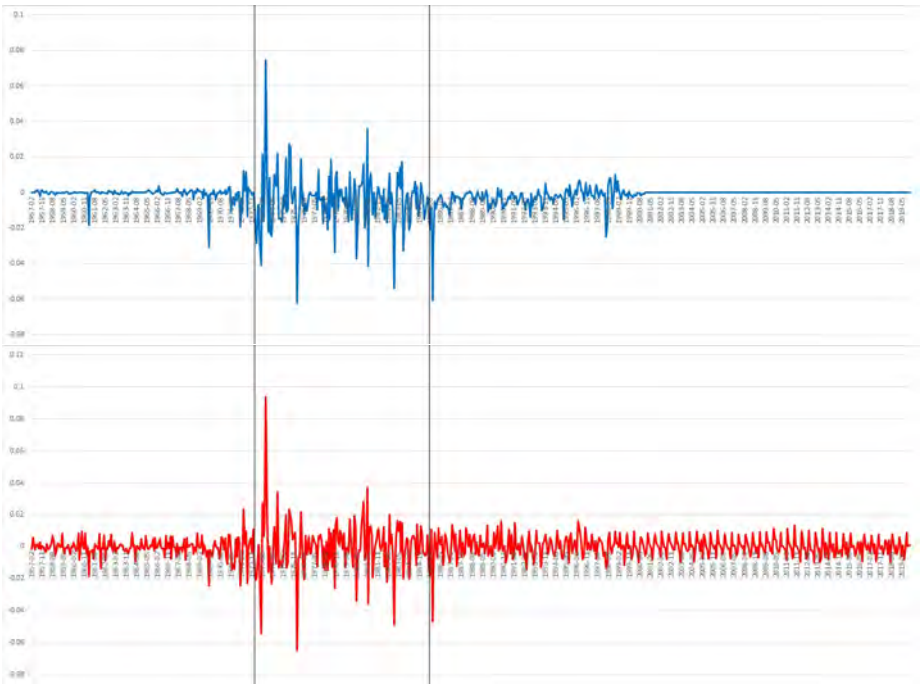

Figure 13: Greece (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

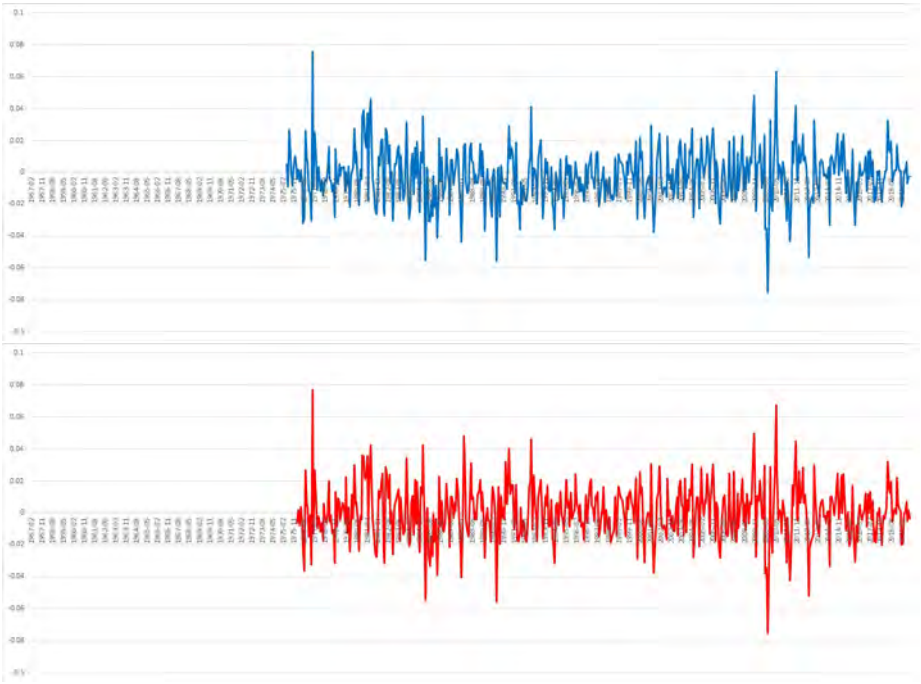

Figure 14: Hungary (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

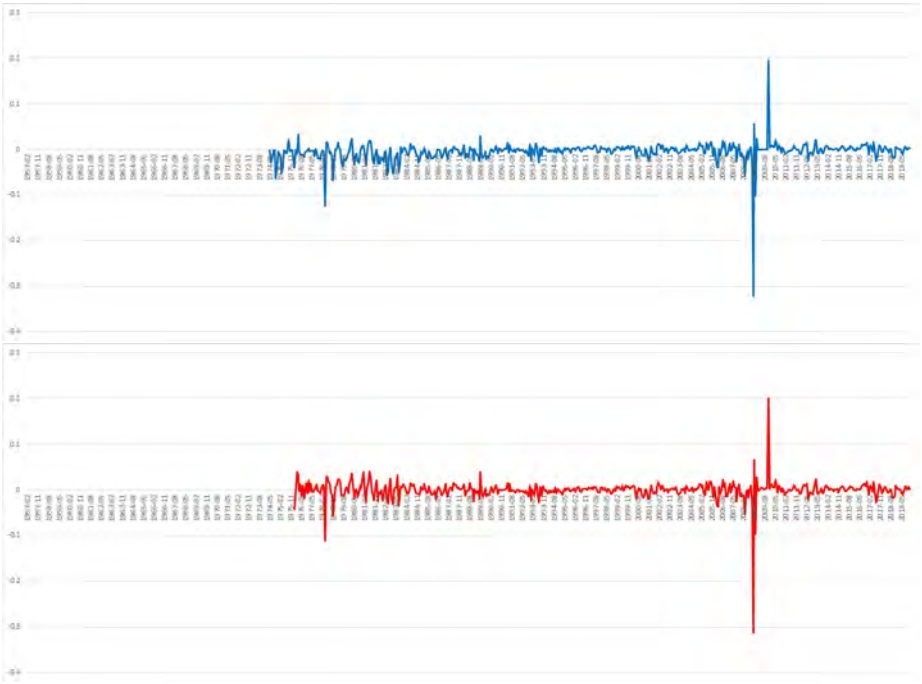

Figure 15: Iceland (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

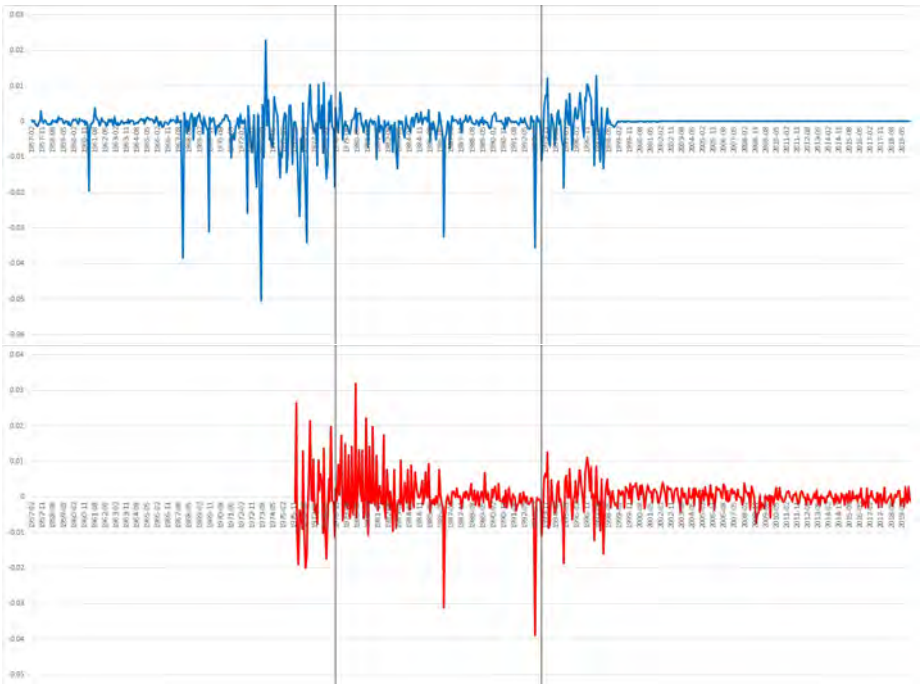

Figure 16: Ireland (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

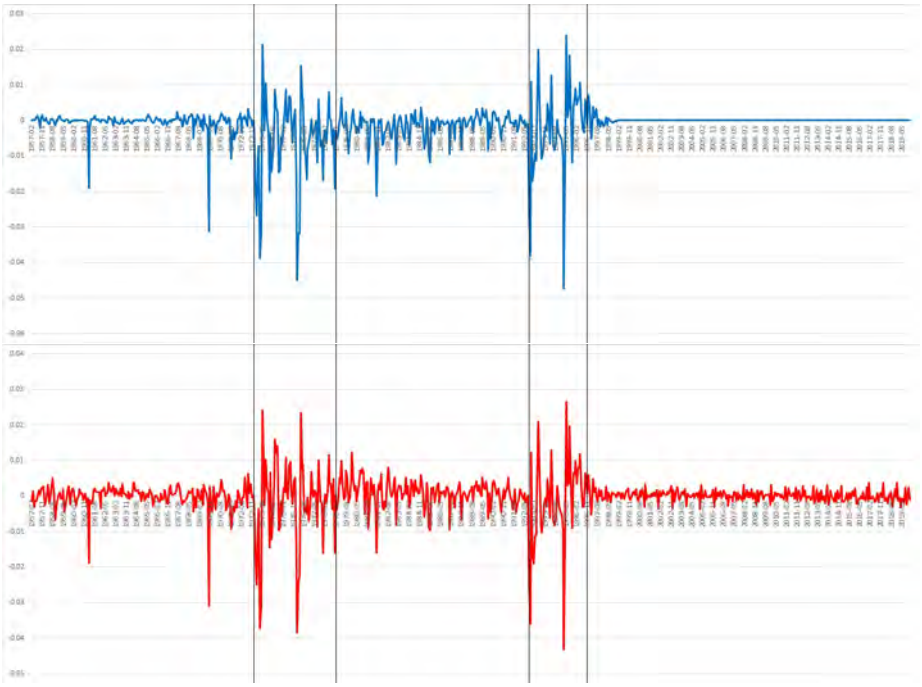

Figure 17: Italy (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

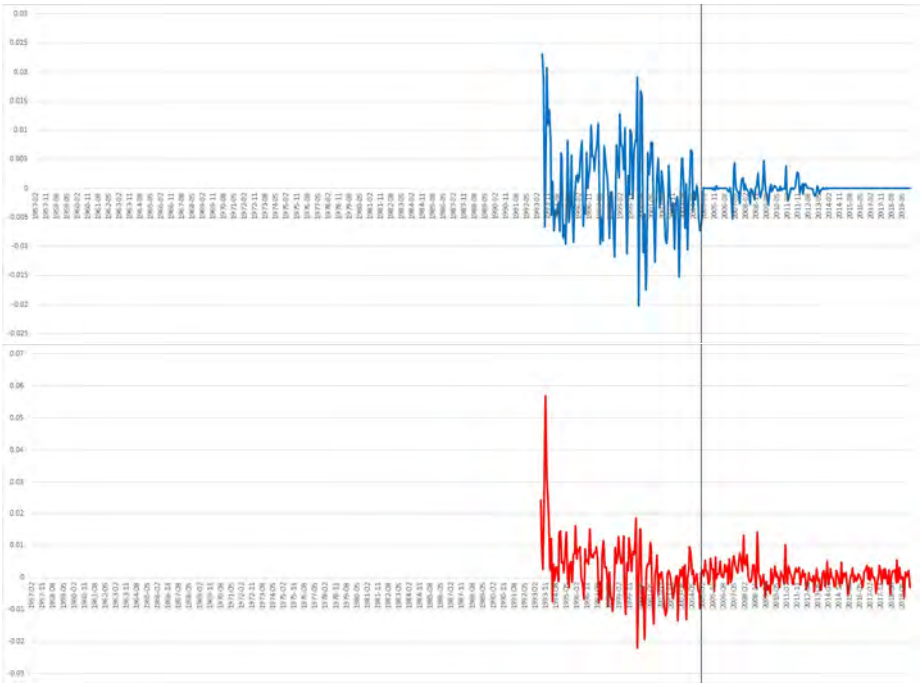

Figure 18: Latvia (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

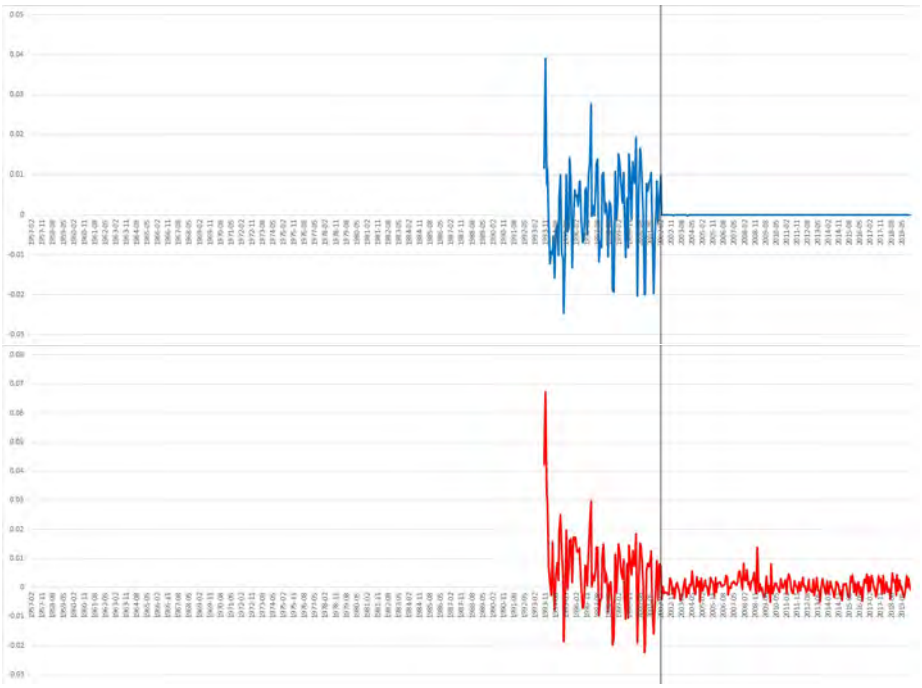

Figure 19: Lithuania (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

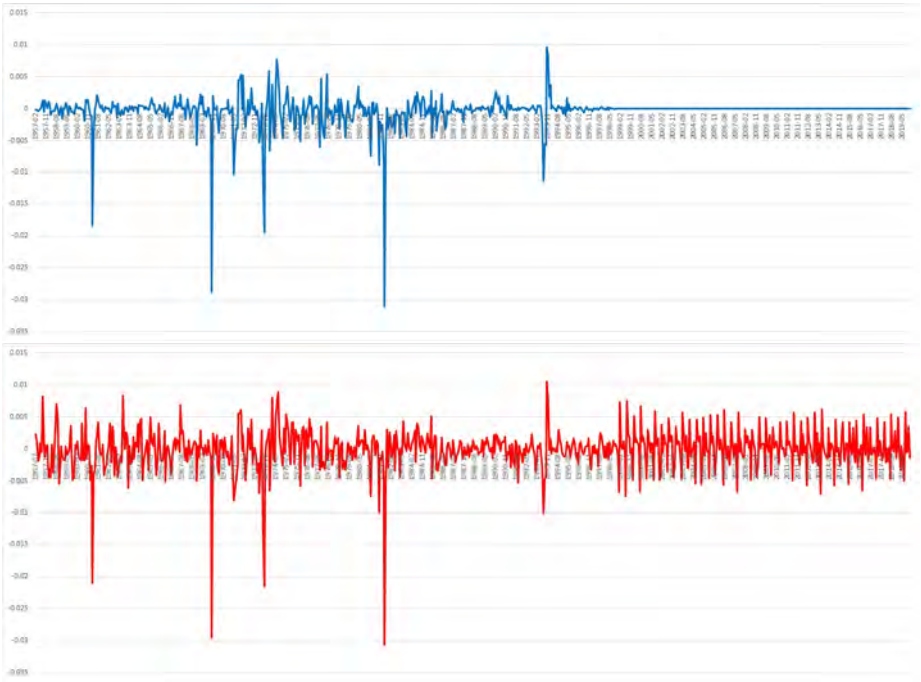

Figure 20: Luxembourg (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

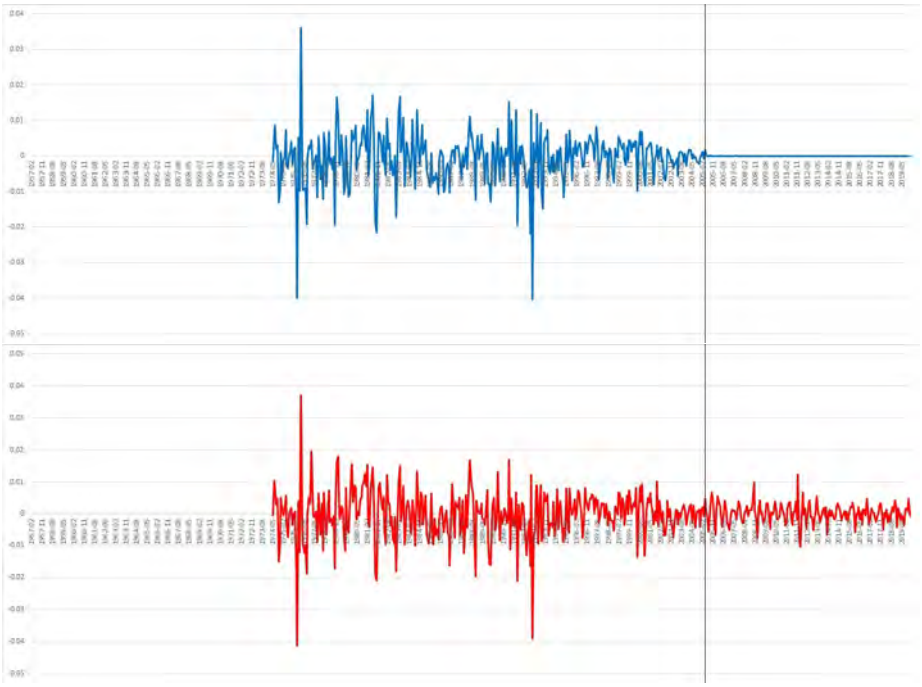

Figure 21: Malta (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

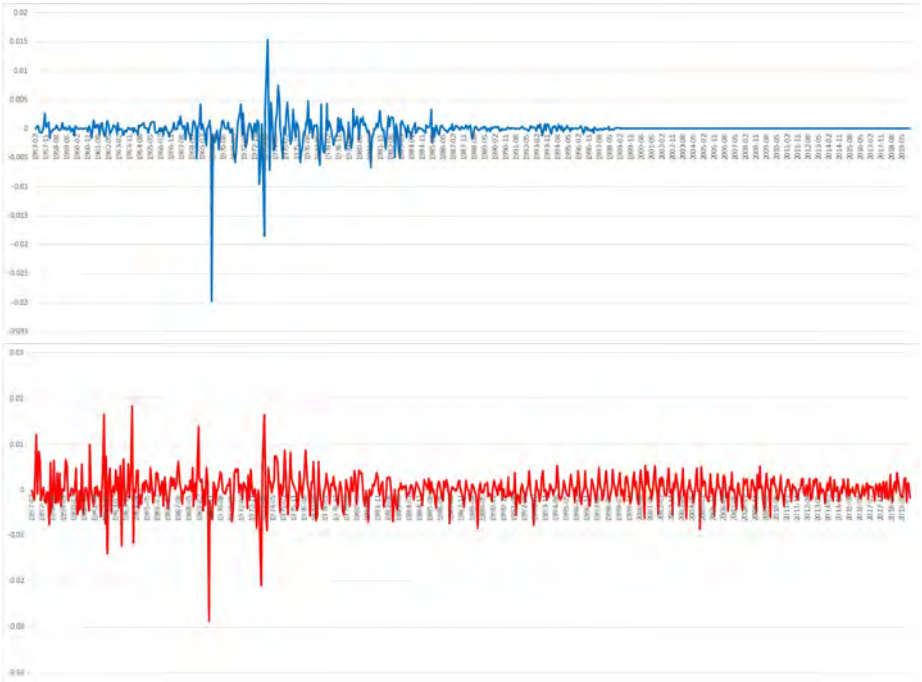

Figure 22: Netherlands (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

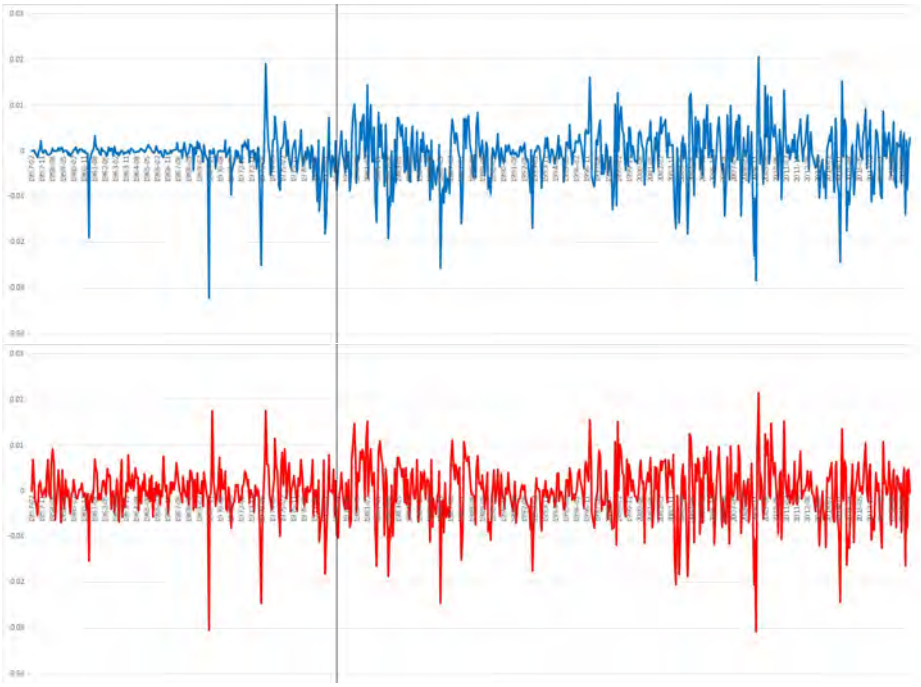

Figure 23: Norway (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

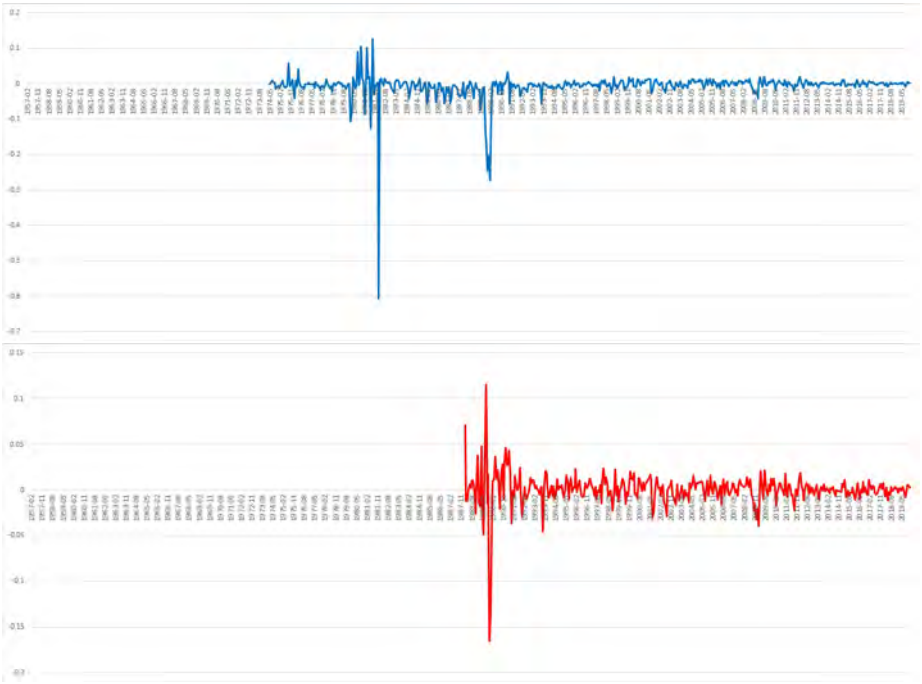

Figure 24: Republic of Poland (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

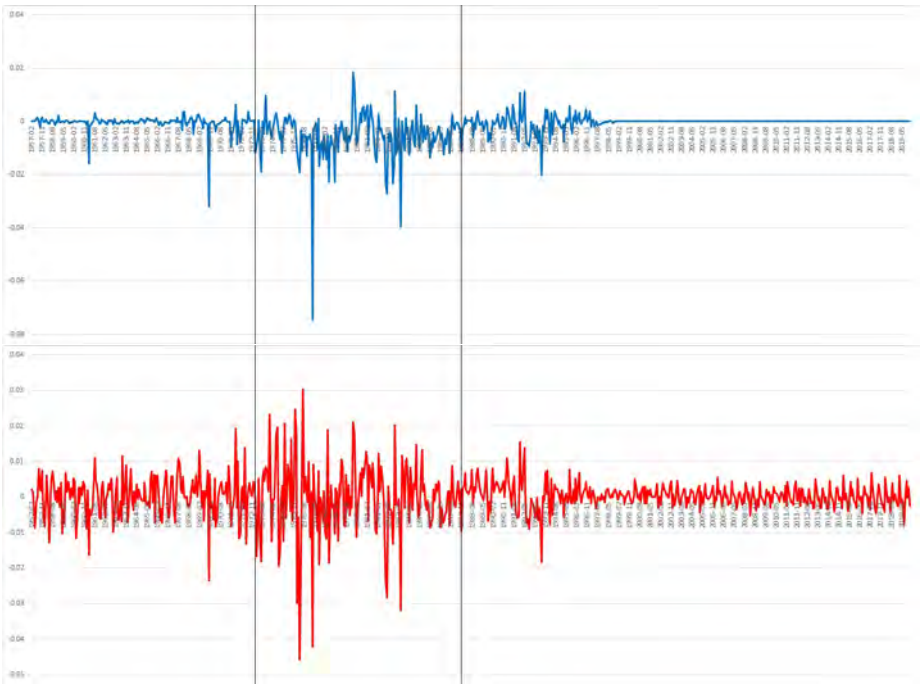

Figure 25: Portugal (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

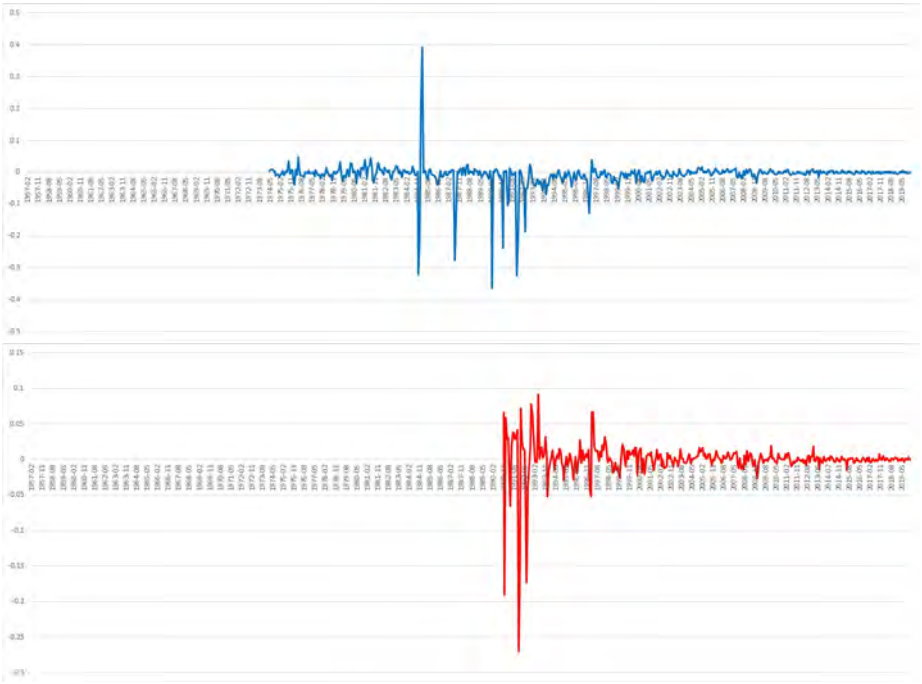

Figure 26: Romania (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

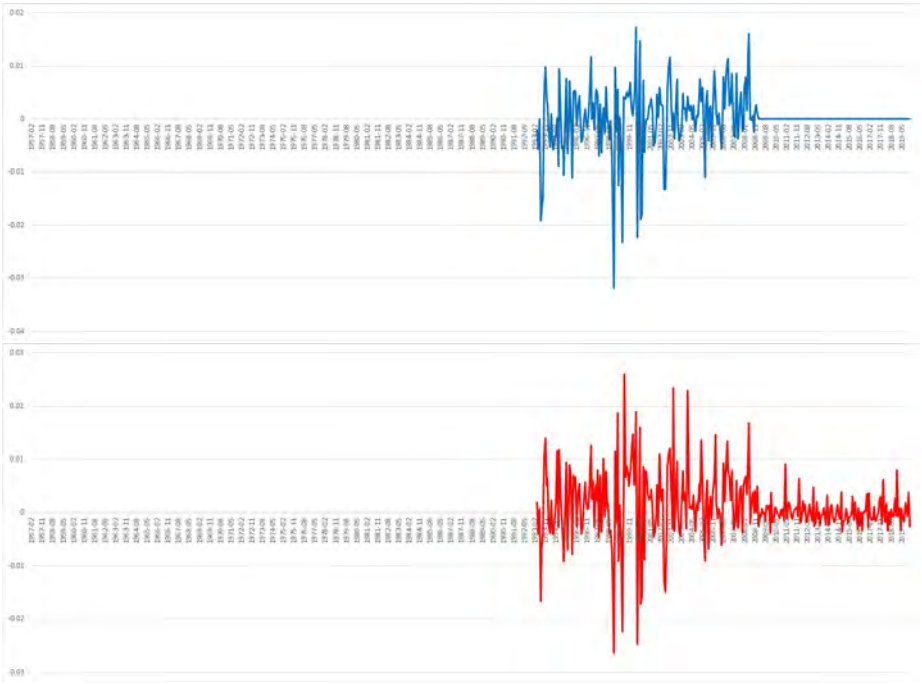

Figure 27: Slovak Republic (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

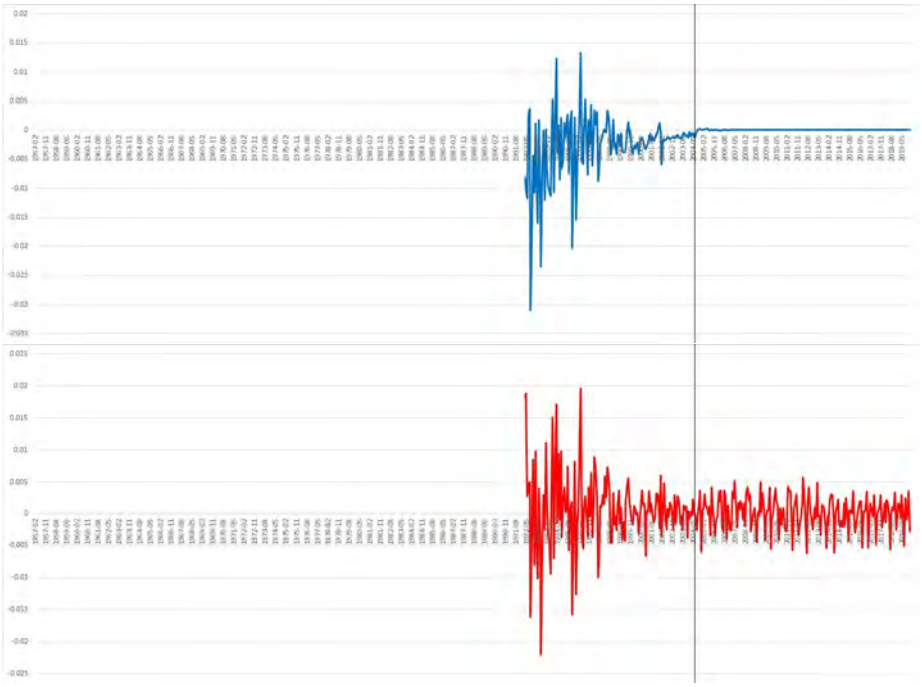

Figure 28: Republic of Slovenia (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

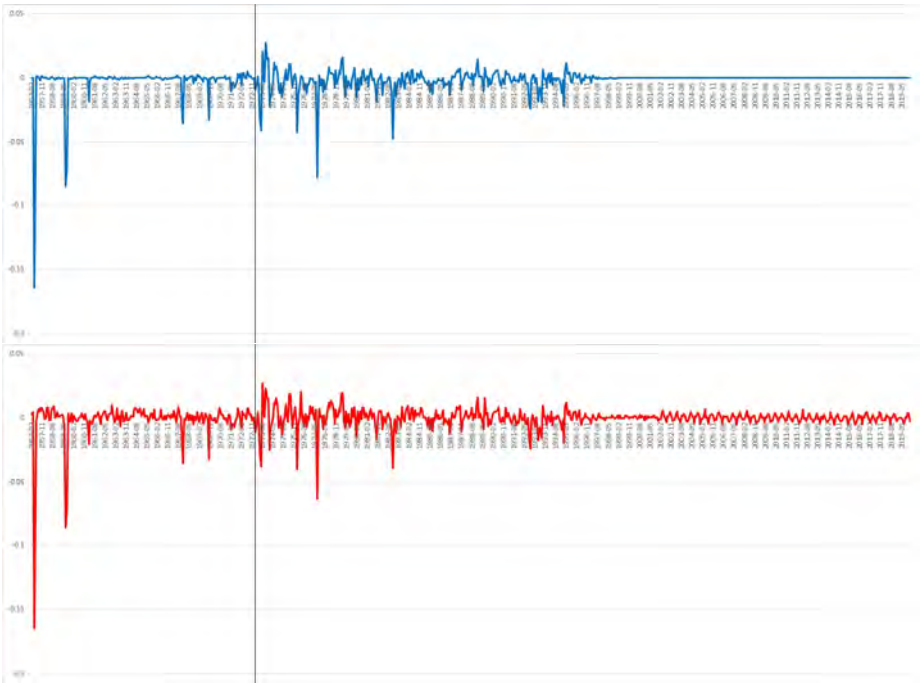

Figure 29: Spain (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

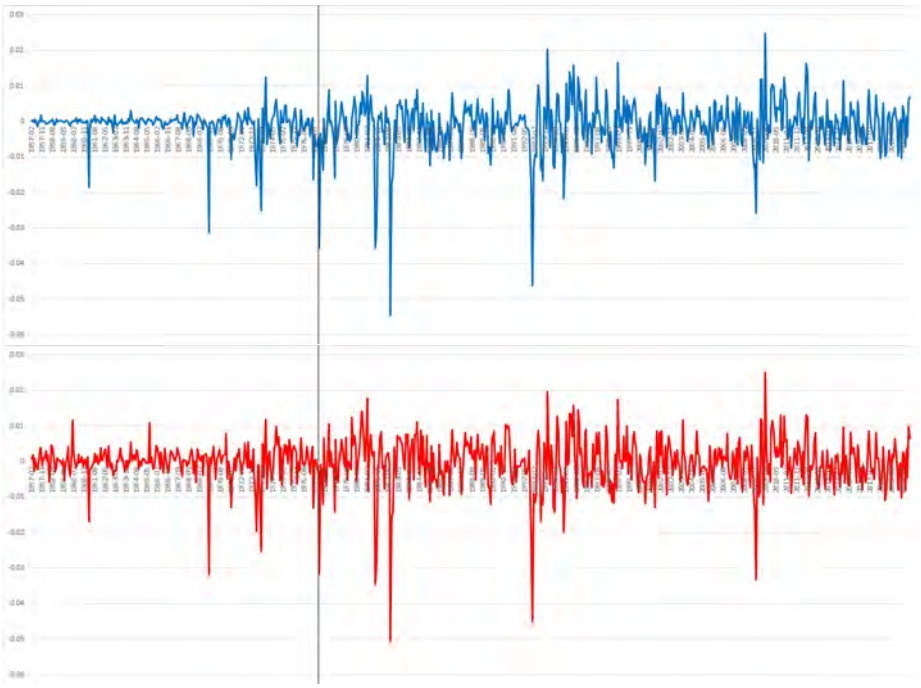

Figure 30: Sweden (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

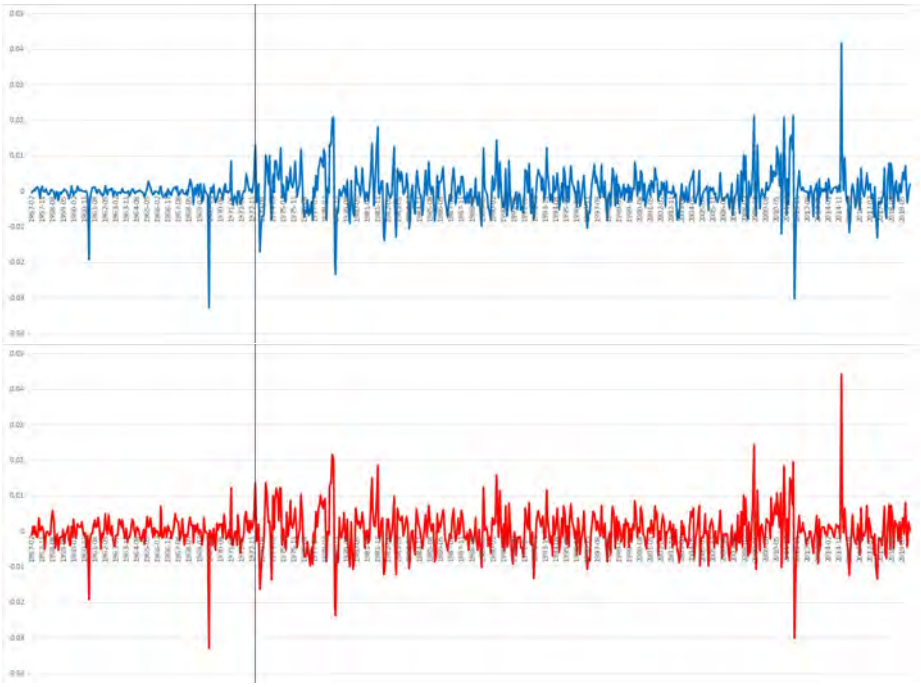

Figure 31: Switzerland (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

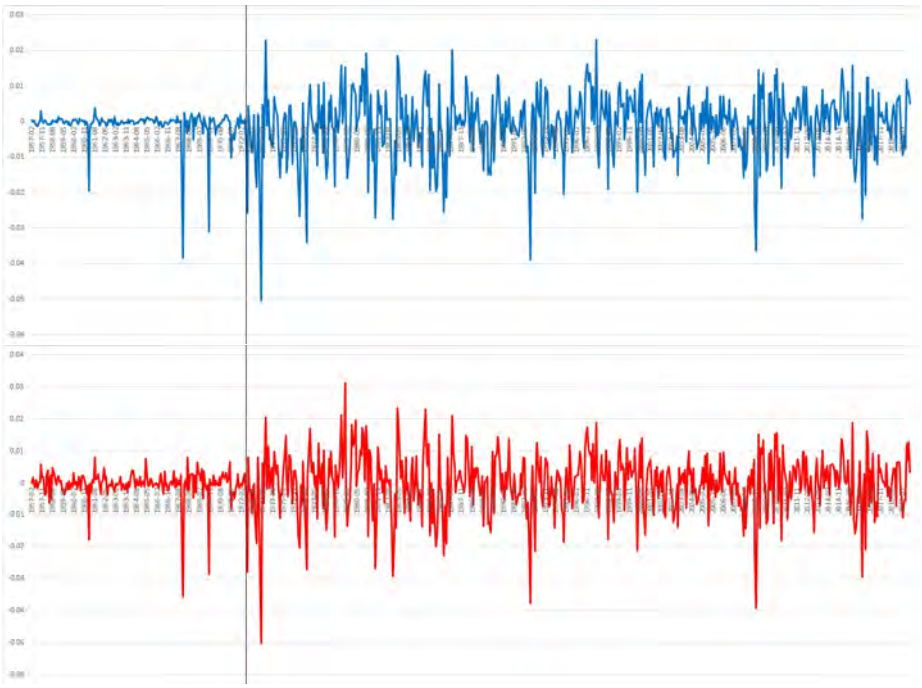

Figure 32: United Kingdom (Foreign Country) and Germany (Home Country)

Note: The nominal exchange rate series is in blue, and the real exchange rate series is in red. Both series are in logarithmic differences. The vertical lines represent monetary-regime breaks that are identified with the narrative and econometric approaches.
Source: The Exchange Rates Portal of the Bank of Italy and the International Financial Statistics of the International Monetary Fund. For details, see section I.

Table 2: Available Time Windows for the Exchange Rate Series

Country	Nominal Exchange Rate	Real Exchange Rate
Austria	1/1957-12/2019	1/1957-12/2019
Belgium	1/1957-12/2019	1/1957-12/2019
Bulgaria	4/1974-12/2019	1/1991-12/2019
Republic of Croatia	6/1994-12/2019	6/1994-12/2019
Cyprus[a]	4/1974-12/2019 (4/1974-6/2007)	4/1974-12/2019 (4/1974-6/2007)
Czech Republic	3/1993-12/2019	3/1993-12/2019
Denmark	1/1957-12/2019	1/1967-12/2019
Republic of Estonia	2/1993-12/2019	2/1993-12/2019
Finland[a]	1/1957-12/2019 (1/1957-12/1998)	1/1957-12/2019 (1/1957-12/1998)
France[ab]	1/1957-12/2019 (1/1970-12/1998)	1/1957-12/2019 (1/1970-12/1998)
Greece[a]	1/1957-12/2019 (1/1957-5/2000)	1/1957-12/2019 (1/1957-5/2000)
Hungary	4/1975-12/2019	1/1976-12/2019
Iceland	4/1974-12/2019	1/1976-12/2019
Ireland[a]	1/1957-12/2019 (1/1957-12/1998)	11/1975-12/2019 (11/1975-12/1998)
Italy[a]	1/1957-12/2019 (1/1957-12/1998)	1/1957-12/2019 (1/1957-12/1998)

Country	Nominal Exchange Rate	Real Exchange Rate
Latvia[a]	6/1993-12/2019 (6/1993-6/2013)	6/1993-12/2019 (6/1993-6/2013)
Lithuania[a]	9/1993-12/2019 (9/1993-6/2014)	9/1993-12/2019 (9/1993-6/2014)
Luxembourg	1/1957-12/2019	1/1957-12/2019
Malta[a]	4/1974-12/2019 (4/1974-6/2007)	4/1974-12/2019 (4/1974-6/2007)
Netherlands	1/1957-12/2019	1/1957-12/2019
Norway	1/1957-12/2019	1/1957-12/2019
Republic of Poland	4/1974-12/2019	1/1988-12/2019
Portugal[a]	1/1957-12/2019 (1/1957-12/1998)	1/1957-12/2019 (1/1957-12/1998)
Romania	4/1974-12/2019	10/1990-12/2019
Slovak Republic[a]	3/1993-12/2019 (3/1993-6/2008)	3/1993-12/2019 (3/1993-6/2008)
Republic of Slovenia[a]	3/1992-12/2019 (3/1992-6/2006)	3/1992-12/2019 (3/1992-6/2006)
Spain[abc]	1/1957-12/2019 (1/1970-12/1998)	1/1957-12/2019 (1/1970-12/1998)
Sweden	1/1957-12/2019	1/1957-12/2019
Switzerland	1/1957-12/2019	1/1957-12/2019
United Kingdom	1/1957-12/2019	1/1957-12/2019

Note: [a]For the European countries in the euro area, I run the two structural-break tests for the time window in parentheses. [b]Given that the L&M test is particularly sensitive to observations in the series that significantly depart from the rest, I run the L&M test only over the period January 1970 to December 1998.[c]The nominal exchange rate in March 1964 is missing; I construct it by linear interpolation.

Table 3: Historical Sources for the Narrative Approach

Country	Historical Source
Austria	James (2014) & Austrian Central Bank Paper
Belgium	James (2014)
Bulgaria	International Monetary Fund Policy Discussion Paper
Republic of Croatia	Croatian National Bank Statement
Cyprus	Central Bank of Cyprus Working Paper
Czech Republic	European Commission Working Paper
Denmark	James (2014)
Republic of Estonia	International Monetary Fund Staff Paper
Finland	James (2014)
France	James (2014)
Greece	James (2014)
Hungary	Hungarian National Bank Statement
Iceland	Government of Iceland Report
Ireland	James (2014)
Italy	James (2014)

Country	Historical Source
Latvia	Advances in Systems Science and Applications Paper
Lithuania	International Monetary Fund Working Paper
Luxembourg	James (2014)
Malta	European Central Bank Statement
Netherlands	James (2014)
Norway	James (2014) & Norges Bank Staff Memo
Republic of Poland	Bank for International Settlements Paper
Portugal	James (2014)
Romania	National Bank of Romania Statement
Slovak Republic	European Commission Working Paper
Republic of Slovenia	European Central Bank Statement
Spain	James (2014)
Sweden	James (2014)
Switzerland	James (2014)
United Kingdom	James (2014)