Exchange Rate Behavior with Negative Interest Rates: Some Early Negative Observations

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Comments Welcome

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Abstract

This paper examines exchange rate behavior during the recent period with negative nominal interest rates. We use a daily panel of data of 61 currencies from Jan 2010 through May 2016; during this time five economies (Denmark, EMU, Japan, Sweden, and Switzerland) experienced negative nominal interest rates. We examine both effective exchange rates and bilateral rates, the latter typically measured against the Swiss franc since Switzerland has had the longest period of negative nominal rates. We examine exchange rate volatility, exchange rate changes, deviations from uncovered interest parity, and profits from the carry trade. We find that negative interest rates seem to have little effect on observable exchange rate behavior.

Keywords: volatility, deviation, uncovered, interest, parity, carry, trade, daily, data, nominal, effective.

JEL Classification Numbers: F31, G15

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1. Introduction

This paper examines exchange rate behavior under during the recent period of negative nominal interest rates. We use a panel of daily data between January 2010 and May 2016 for 61 economies to examine exchange rate volatility and deviations from uncovered interest parity.[1] During this time, five economies (Denmark, EMU, Japan, Sweden, and Switzerland) experienced nominal interest rates that were (non-trivially) negative.[2] Our results are mostly negative; we find little evidence that negative interest rates have had any substantial effect on exchange rates.

2. Literature

There is a small but growing literature on the effects of negative nominal interest rates. References of relevance include Viñals, Gray and Eckhold (2016), and Arteta et al (2016). The key questions addressed about negative nominal rates usually concern their efficacy and limitations in stimulating economic growth and inflation, and their effect on bank profitability and financial stability. Little attention is usually paid to the exchange rate, though it is widely recognized that negative nominal interest rates were sometimes introduced to deter capital inflows, as in the cases of Denmark and Switzerland.

The literature gives us little reason to believe that the introduction or maintenance of negative nominal interest rates has a material effect on exchange rate behavior. For instance, Arteta et al (2016) write "The currencies of NIRP [negative interest rate policy] countries have shown varied responses … Enduring changes in exchange rates and equity market indexes cannot be discerned from other factors affecting them over time … the exchange rate response [of emerging and developing economies] varied considerably across countries, both in terms of size and direction …" while Viñals et al (2016) write "The impact of negative central bank rates on the exchange rate has been mixed …"

Still, there is reason to look for a discontinuity in exchange rate behavior around a nominal interest rate of zero. Perhaps the shocks that drive nominal interest rates negative are different from those when rates are positive but low? Perhaps foreign exchange market participants perceive there to be some discontinuous effect because of subtle changes to arbitrage conditions like covered interest parity? Accordingly, we conduct an open-minded empirical exploration.

3. The Data Set

We are interested in understanding exchange rate behavior during the contemporary period of negative nominal interest rates. Negative interest rates are a recent phenomenon, so we wish to maximize the potential scope of a necessarily limited data set. We begin the data set in January 2010, so as to reduce the after-effects of the Global Financial Crisis and Great Recession while also including a period of comparable data before the onset of negative interest rates. We rely on the highest frequency of data (daily) that is reliably available for a wide range of countries, since we hope to bring a large cross-section to bear on a problem with a necessarily limited time-series span. We treat Switzerland as the base country for much of the analysis, because Switzerland was the first economy to hit negative interest rates recently.[3] During the sample, Switzerland experienced 827 days of negative nominal interest rates; it has also experienced the largest negative interest rates in absolute value.[4] Accordingly, we convert bilateral dollar (and pound) rates to Swiss rates (foreign currency per Swiss franc), assuming trilateral arbitrage. However, for sensitivity analysis we also use the US dollar, the pound sterling and the Euro as alternative bases.

Our spot exchange rates are closing rates calculated by the WM Company based on data provided by Reuters at or around 4pm London time.[5] These rates are determined close to the middle of the 'global day' (11am New York time) during a time of high liquidity in the global foreign exchange market. We primarily use mid-point bilateral US dollar rates as primitive data, but check and supplement with British pound rates. Forward exchange rates are handled similarly; since we often compare forward with *ex post* realized future spot rates, we use a one-month maturity to maximize the number of data points available, acknowledging that this necessarily limits the scope of our investigation.[6] We obtained series for all currencies available, and are confident that this represents a large fraction of the actively traded foreign exchange activity; the data set covers essentially all currencies of relevance.[7] Daily effective exchange rate series are drawn from the Bank of England (eleven are available).

Our default measure of interest rates comes from the British Bankers Association (BBA) interest settlement rates, known as LIBOR fixings.[8] These rates are available for five economies (EMU, Japan, Switzerland, the UK and the USA). When LIBOR rates are not available we occasionally use two other interest rates for sensitivity analysis: 1-month Euro-currency interbank deposit rates whenever possible, and also 1-month domestic interest rates. The former are available for Australia, Canada, Denmark, EMU, Hong Kong, Japan, Norway, New Zealand, South Africa, Sweden, Switzerland, UK, and USA; they have been used in this context by Burnside et al (2010). The latter are 30-day interest rates from Datastream's "National Interest Rates." Inter-bank offer rates are chosen if available; these are usually mid-market, collected around local closing time. If inter-bank offer rates are unavailable, deposit rates are substituted. As another check, we sometimes use dates for negative *official* interest rates in place of negative *market* rates, typically derived from monetary policy announcements. All interest rates are annualized.

We use IMF classifications for both advanced economies and *de facto* exchange rate regimes. We define a month as 21 business days.

The data set has been massaged in a number of other ways. We corrected some transcription errors, and throw out data for Jordan (since interest rates never change), the Ukraine (since the forward rate doesn't move after June 2015), and Venezuela (since it is from the official, not black, market before March 2016). We are left with rates for 61 economies (a list is tabulated in the longer version of this paper, available online).

4. First Impressions

We begin our first look at the data with Figure 1, which provides simple time-series plots of the Swiss effective exchange rate and the (annualized 1-month LIBOR) Swiss interest rate. Swiss interest rates (the dashed line labelled on the left axis) first went negative briefly in August 2011, shortly after a sudden appreciation of the Swiss franc (the solid line labelled on the right) triggered a relaxation of monetary policy by the Swiss National Bank (SNB). The SNB diagnosed "massive overvaluation" and loosened to protect Swiss competitiveness and reduce deflationary pressures. The appreciation was quickly reversed after a series of SNB policy innovations including quantitative easing, swap transactions, and most radically, the establishment of a floor on the Euro/Swiss Franc exchange rate on September 6 2011. Swiss interest rates then fluctuated around zero until the dramatic events of mid-January 2015 when the SNB removed the exchange rate floor, lowered interest rates to substantially negative levels, and allowed the franc to appreciate. It is important to recognize that Switzerland imposed negative nominal rates as a response to exchange rate pressures; this endogeneity also characterizes Denmark (which fixes to the Euro).[9]

The temporary spike of the Swiss franc in August 2011 and its jump appreciation of January 2015 are important features of this data set. A couple more subtle features are also interesting. First, the negative interest rates cluster into two groups: the near-zero rates that existed for three and a half years before Jan 2015, and the substantially negative rates thereafter. Also, the *volatility* of the effective exchange rate seems unrelated to the interest rate *level*, with the exception of the 8/2011 and 1/2015 events.

Where Figure 1 portrays *Swiss* interest rates and the Swiss *effective* exchange rate, Figure 2 provides plots for *national* (LIBOR) interest rates and *bilateral* Swiss exchange rates for the four most important currencies: the American dollar, the Euro, the Yen, and the Pound Sterling. In each case, the events of both August 2011 and January 2015 are clearly visible (and marked). The December 2015 increase in American interest rates is clearly visible, as is the move to negative Japanese interest rates of late January 2016. Again, the volatility of the (four bilateral) exchange rates seems unrelated to the interest rate level, with the exception of the 8/2011 and 1/2015 events; the only exception is the low volatility during the Euro/Swiss Franc floor.

5. Exchange Rate Volatility and Interest Rate Levels

We now investigate whether negative interest rates are systematically associated with exchange rate volatility. There is no theoretical reason to expect a relationship, either positive or negative, between exchange rate volatility and nominal interest rate levels; hence our investigation is exploratory in nature. Since *bilateral* exchange rates necessarily involve two currencies and thus two interest rates, it is easiest to visualize the relationship between a single interest rate level and the volatility of an *effective* exchange rate. To measure volatility, we use the standard deviation of the first-difference in the log of the daily log effective exchange rate, calculated over the (21 business) days that compose a month.[10] Figure 3 then scatters this monthly measure of Swiss effective exchange rate volatility against the level of Swiss interest rates; we also include a fitted least-squares regression line.[11]

There are three outliers in Figure 3; each of these spikes in Swiss exchange rate volatility is clearly associated with the events that began and ended the Swiss exchange rate floor. But whether or not one ignores the outliers, exchange rate volatility does not seem to vary systematically as interest rates vary between small positive and substantially negative levels.

Figure 4 consists of graphs analogous to Figure 3, one for each of the four major currencies (the American dollar, Euro, Yen and pound sterling) as well as a pair for the other economies that have experienced negative interest rates (Denmark and Sweden). Each graph scatters effective exchange rate volatility against the domestic interest rate; least squares regression lines are also included. In no case, is there a strong linkage between exchange rate volatility and the interest rate level. All of the major economies kept interest rates low during the entire period, while the two Scandinavian economies used somewhat wider ranges. But the negative interest rates experienced by four economies seem unassociated with either higher or lower exchange rate volatility.[12]

Figures 3 and 4 scatter the volatility of a country's *effective* exchange rate volatility against its interest rate. Figure 5 contains *bilateral* (Swiss Franc) analogues for nine other economies; in each case exchange rate volatility is graphed against the national interest rate (along with fitted regression lines, as usual). In almost all cases, there is no clear relationship bilateral exchange rate volatility and the level of the interest rate. The one exception is the case of the Russian ruble which demonstrates an economically and statistically significant relationship.[13] However, the average Russian interest rate exceeded 7% during the sample, and its minimal value was 3.36%, so the Russian data has little to say concerning negative nominal interest rates.

Bilateral data for all (60) countries are combined together in Figure 6. This figure must be interpreted carefully, as the observations are highly dependent across countries; when the American dollar is highly volatile vis-à-vis the Swiss franc, it is also likely that the Canadian dollar will be highly volatile. The top-left graph scatters exchange rate volatility against the *Swiss* interest rate on the x-axis; as with Figure 3 (the analogue with Swiss *effective* exchange rate volatility instead of Swiss *bilateral* exchange rate volatility), there is little clear pattern. The top-right graph scatters exchange rate volatility against *national* interest rates on the x-axis. National interest rates range up to almost 30%; since our primary interest lies in the effects of negative nominal interest rates, the bottom two graphs zoom in further. In the bottom-left, we graph observations when national interest rates are below .6%, a level chosen since the lowest (non-Swiss) national interest rate in the sample is -.59%. The bottom-right portrays only data when the national interest rate is between -.2% and .2%.[14] There is little sign of any substantial change in exchange rate volatility as the nominal interest rate falls below zero.[15]

While the evidence in Figures 3-6 is persuasive, it is ocular. We provide a little more rigor in Table 1, which presents regressions of exchange rate volatility on interest rate levels. In particular, we estimate:

$$\sigma(eff_{i,\tau}) = \alpha + \beta interest_{,\tau} + \gamma NegDummy_{i,\tau} + \xi_{i,\tau} \quad (1)$$

where:

- $\sigma(eff_{i,\tau})$ is the volatility of the effective exchange rate for economy i during month τ, calculated as the standard deviation over the month of the daily first-differences in log effective exchange rate
- interest is the 1-month nominal interest rate (LIBOR where available, Euro-deposit rate if not),
- $NegDummy_{i,\tau}$ is a binary dummy variable that is one if economy i experienced negative nominal interest rates at time τ and is otherwise zero,
- α, β, and γ are coefficients to be estimated, and
- ξ represents all residual determinants of exchange rate volatility.

Since (1) is a panel pooled across both countries and time, we include country-specific fixed effects for each of the eleven economies for which we have effective exchange rates data (Australia, Canada, Denmark, Euro, Japan, New Zealand, Norway, Sweden, Switzerland, UK, and USA), to account for cross-country heterogeneity.

The top row of Table 1 tabulates estimates of (1) and confirms the impression given by the figures; there is no close linkage between exchange rate volatility and the level of the nominal interest rate. Removing the dummy variable for negative nominal interest rates does not change this conclusion; the coefficients are economically and statistically insignificant. The remainder of Table 1 show that this result is insensitive to reasonable perturbations of the econometrics. These include adding time-specific fixed effects, substituting official (for market) interest rates, and dropping a) fixed exchange rate economies, b) the half of the sample with the highest nominal interest rates or c) observations with residuals that are large (at least two absolute standard deviations from the mean). One does find significant effects if country fixed effects are excluded or the analysis uses only 2012; we consider these to be uninteresting findings.

Succinctly, there appears to be no strong relationship between exchange rate volatility and the level of nominal interest rates, at least for this sample of data. In particular, negative nominal interest rates are not associated with noticeably more or less exchange rate volatility.

6. The Relationship between *Ex Post* Exchange Rate Changes and the Forward Premium

Exchange rates and interest rates are tightly linked in theory through interest parity conditions. *Covered* interest parity (CIP) is an arbitrage condition linking the forward premium – the spread of forward exchange rates over spot – to the interest rate differential.[16] *Uncovered* interest parity (UIP) is a speculative condition that links expected or actual exchange rate changes to the forward premium (or equivalently, in the presence of CIP, the interest differential); Engel (2014) provides a recent survey. In this section, we examine UIP and deviations from UIP during the era of negative nominal interest rates.

In Figure 7, we scatter the *ex post* one-month change in the bilateral Swiss exchange rate, $\log(s_{t+21})-\log(s_t)$ against the corresponding forward premium $\log(f_{t+21,t})-\log(s_t)$, where s_t is the spot exchange rate (foreign currency/Swiss Franc) quoted on day t, and $f_{t+21,t}$ is the forward exchange rate quoted on day t for delivery in 21 business days (one month). Since both one-month exchange rate changes and forward premia are highly auto-correlated at the daily frequency, we graph only one bilateral observation for each business month; more on this below.[17] Since bilateral exchange rate changes are correlated across economies, considerable cross-observation dependency remains (when the Swiss Franc appreciates against the Japanese Yen, it is likely to appreciate against the Korean Won); more on this too below.[18]

The top-left graph of Figure 7 presents the entire sample of (almost 5000) observations available for all country-months. *Ex post* exchange rate changes are positively correlated with forward premia, but only loosely. As can be seen in the top-right graph, this linkage stems from the observations when at least one of the two underlying interest rates is negative. But even for this part of the sample, there is no strong relationship between forward premia and subsequently realized exchange rate changes. Separate graphs scatter the data when both interest rates are positive and negative; in both cases the data are even cloudier.

In Figure 8, we focus more tightly on the same relationship – between *ex post* exchange rate changes and forward premia – during periods of very low Swiss interest rates. The top-left presents a histogram of Swiss interest rates, showing that the data are bunched into two groups, at approximately (-.05, .15) and (-1, -.75). The latter cluster of observations is scattered in the lower-left graph. These observations – where the Swiss interest rate is substantially negative – demonstrate only a loose relationship between actual exchange rate changes and forward premia; the data are essentially a messy cloud. Still, the more interesting evidence is contained in the two graphs on the right-hand side of the figure. Both scatter *ex post* exchange rate changes against forward premia; the top-right graph portrays observations where the Swiss interest rate is small and positive (between 0 and .1%), while the analogue below presents the data when the same interest rate is small and negative (between 0 and -.1%). Both the slopes are positive, and that for negative Swiss interest rates is significantly different from zero. The two different samples portray relationships that look similar and cloudy; the relationship between exchange rate changes and the forward premium does not seem to differ substantially between small positive and small negative interest rates.

The bilateral Swiss data of Figure 8 show a statistically significant difference in the relationship between *ex post* exchange rate changes and the forward premia on either side of the zero interest rate. Accordingly, we investigate this further in Figure 9, but substituting the Euro as the base currency. As is apparent in Figure 2, the Euro has a large number of observations of interest rates that are close to zero, both positive and negative. We take advantage of this on the right-hand side of Figure 9; this is the Euro analogue to the Swiss data of Figure 8, but portrays the data when the Euro interest rate is between 0 and .05% (above) or between 0 and -.05% (below).[19] The pair of graphs look similar.[20]

In summary, our ocular inspection indicates that the relationship between *ex post* exchange rate changes and the forward premium is little affected by the presence or absence of negative nominal interest rates. Still, a more rigorous examination seems appropriate. Accordingly, we examine deviations from uncovered interest parity using standard regression techniques in the longer (online) version of this paper. It delivers similar results.

It seems reasonable to summarize the results of this section as indicating that negative nominal interest rates do not have a large effect on the relationship between forward premia and subsequent changes in spot exchange rates. If negative nominal interest rates persist, it will be possible for future researchers to extend this one-month analysis to longer horizons.

7. Returns from the Carry Trade

Given the pervasive evidence of the failure of uncovered interest parity, it is unsurprising that financial strategies have been developed to take advantage of UIP deviations. One popular technique, know colloquially as the “carry trade” is a strategy in which an investor borrows money in a low interest rate country, converts these funds on the spot foreign exchange market and invests these funds in a country with higher interest rates. When the long position reaches maturity, the latter funds are converted at the future spot rate to repay the initial loan. Excess returns result if the interest rate differential is not offset by exchange rate depreciation. The carry trade is risky, but common in the foreign exchanges; see, e.g., Burnside et al (2010). Accordingly, we now examine if carry trade returns are affected by the presence of negative nominal interest rates.

We begin by replicating returns from the carry trade. We construct these as follows.

1. We begin by treating the Swiss Franc as the default currency in which to measure cumulative returns.[21]
    a. We also use the Pound Sterling and the American dollar as bases.
2. Each month, we sort all 60 currencies (excluding the base currency, the Swiss Franc) by the level of their interest rate. We use interest rates implied by CIP through the forward premium.
    a. We also consider interest rates for which we have explicit data. We use LIBOR rates where available, London Euro-currency deposit rates when possible if LIBOR is missing, and national interest rates otherwise.
3. After sorting on interest rates, we form two portfolios: a short portfolio with the lowest three interest rates (equally weighted), and a long portfolio with the highest three interest rates (again, equally weighted).
    a. We also consider portfolios with five and ten currencies.
4. We construct the returns for the long, short and long minus short portfolios.
5. Each month, we repeat steps 2-4.

We are left with (three base currencies x two interest rate measures x three portfolio sizes equals) eighteen alternative measures of carry trade returns. Simple time-series plots of these returns, calculated with implicit interest rates, are provided in Figure 10. Consider the top-left graph of the figure. The monthly flow returns from the carry traded are plotted in the thin continuous line which typically fluctuates around zero (using the left-hand axis); these returns are computed with interest rates implicit in the forward premium, and long/short portfolios of three currencies each. The cumulative returns over the entire sample, measured in Swiss Francs, are plotted in the thick dashed line (using the right-hand axis). As one moves from left to right, the number of currencies in the portfolios rises; different rows correspond to different currencies of measurement.

The data in the figure deliver the message that carry trade returns are pervasive but risky. They are systematically higher when fewer currencies are used to form portfolios, and substantially higher when the (more reliable) forward rates are used to determine long/short currencies, rather than explicit interest rate data. None of this is particularly surprising. We view it as a suitable springboard to begin our investigation into the effect of negative nominal interest rates on the carry trade.

In Table 2 we regress monthly flow returns from the (eighteen different measures of the) carry trade on negative nominal interest rates. We use two different measures for the importance of negative nominal interest rates at a point in time: a) the number of currencies with negative nominal interest rates at time t; and b) a dummy variable which is unity if there is at least one currency with a negative nominal interest rate at time t and zero otherwise. That is, we estimate:

$$CARRY_{c,s,i,t} = \alpha + \beta NEG_t + \varepsilon_{c,s,i,t} \quad (5)$$

where

- $CARRY_{c,s,i,t}$ is the monthly flow carry-trade return measured in currency c, with s currencies in both long/short portfolios, using measure i of interest rates (implicit in forward rates/explicit) at month t, and
- NEG_t is a measure of how many negative interest rates there are at time t.

Our results are tabulated in Table 2. Each of the eighteen rows corresponds to a different combination of measurement currency/portfolio size/interest rate measure. The middle column tabulates estimates of β from the continuous measure of NEG_t (*how many* currencies have negative rates at t?), while the right-hand column uses the discrete measure (does *any* currency have a negative rate?). Unfortunately, none of the coefficients is significantly different from zero at standard confidence intervals; they are economically small, and almost half are negative.

We conclude that there is little reason to believe that negative nominal interest rates have affected carry trade returns.

8. Caveats and Conclusions

A few caveats are in order. First, we ignore transactions costs since we use central rates rather than bid and ask rates, an especially relevant issue for the carry trade. Next, given the small number of observations, we have chosen not to do event studies; if the number of economies with negative interest rates rises dramatically, this is a possible route for future research. Indeed, ours is intended to be an exploratory mission, and we are painfully aware our mission is to investigate the effects of negative nominal interest rates during a period in which most economies never experienced them; the few economies with actual data do not have many observations of relevance. This makes us reluctant to make strong or sweeping generalizations.

Negative interest rates have costs for banks, the banking industry, and the financial sector more broadly. These are likely to be larger in the long run than in the short run. We have ignored all such considerations in our short run focus on exchange rate behavior. And we reiterate that negative rates have only affected a small number of economies for a short period of time, so a conservative conclusion seems appropriate. But the data we have do not indicate that negative nominal interest rates have had substantive consequences for exchange rate behavior.

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Table 1: Regressions of Effective Exchange Rate Volatility on Interest Rates

	Interest Rate Level	Dummy, Negative Interest Rate	Observations
Default	.90 (1.52)	1.22 (2.78)	869
Without Negative Rate Dummy	.62 (1.38)		869
Add Time FE	-2.48 (1.50)	-4.81 (2.52)	869
Without Country FE	4.54** (.58)	-12.9** (3.1)	869
Official (not market) interest rates	2.70 (1.62)	7.35* (3.01)	869
2011	.38 (10.9)	n/a	132
2012	9.62** (3.19)	7.04 (4.37)	143
2013	-15.7 (16.7)	3.12 (7.42)	132
2014	-.70 (5.52)	-2.91 (5.66)	143
2015	-11.84 (15.53)	-9.17 (23.29)	132
Without Fixers	-.88 (1.63)	.39 (3.34)	790
Only lowest half by interest rate	-10.75 (7.16)	-2.54 (4.40)	435
Without > |2σ| Outliers	.56 (1.08)	1.53 (1.92)	844

Estimates of equation (1) and variations. Regression coefficients (standard errors in parentheses) for effect of effective exchange rate volatility (regressand) on level of 1-month nominal interest rate (regressor), and dummy variable for negative nominal rate. Intercept and country fixed effects included but not recorded. Coefficients and standard errors multiplied by 100. Monthly data Jan 2010-May 2016 for 11 effective exchange rates (Australia, Canada, Denmark, Euro, Japan, New Zealand, Norway, Sweden, Switzerland, UK, and USA); volatility is monthly standard deviation of daily first-differences of log effective Bank of England exchange rate.

Table 2: Returns from Long-Short Portfolios and Negative Interest Rates

Currency	Portfolio Size	Interest Rates	Number of Negative Interest Rate	Any Negative Interest Rates
Swiss Franc	3	Implicit	.002 (.002)	.006 (.007)
Swiss Franc	5	Implicit	.001 (.001)	.007 (.006)
Swiss Franc	10	Implicit	.000 (.001)	.002 (.004)
Pound Sterling	3	Implicit	.002 (.002)	.007 (.007)
Pound Sterling	5	Implicit	.001 (.001)	.008 (.005)
Pound Sterling	10	Implicit	.000 (.001)	.003 (.004)
American Dollar	3	Implicit	.002 (.002)	.006 (.007)
American Dollar	5	Implicit	.001 (.001)	.007 (.005)
American Dollar	10	Implicit	.001 (.001)	.004 (.004)
Swiss Franc	3	National	-.003 (.002)	-.005 (.007)
Swiss Franc	5	National	-.001 (.001)	-.001 (.005)
Swiss Franc	10	National	-.001 (.001)	-.001 (.004)
Pound Sterling	3	National	-.002 (.002)	-.003 (.008)
Pound Sterling	5	National	-.001 (.001)	-.000 (.005)
Pound Sterling	10	National	-.001 (.001)	-.000 (.004)
American Dollar	3	National	-.001 (.002)	.000 (.008)
American Dollar	5	National	-.001 (.001)	.001 (.005)
American Dollar	10	National	-.001 (.001)	-.000 (.004)

Coefficients for effect of negative interest rates on excess returns from long-short portfolios. Each cell comes from a different regression. Coefficients significantly different from zero at .01 (.05) significance level marked with one (two) asterisk(s). Intercepts included but not recorded. 76 monthly observations, Jan 2010-May 2016 for 61 currencies.

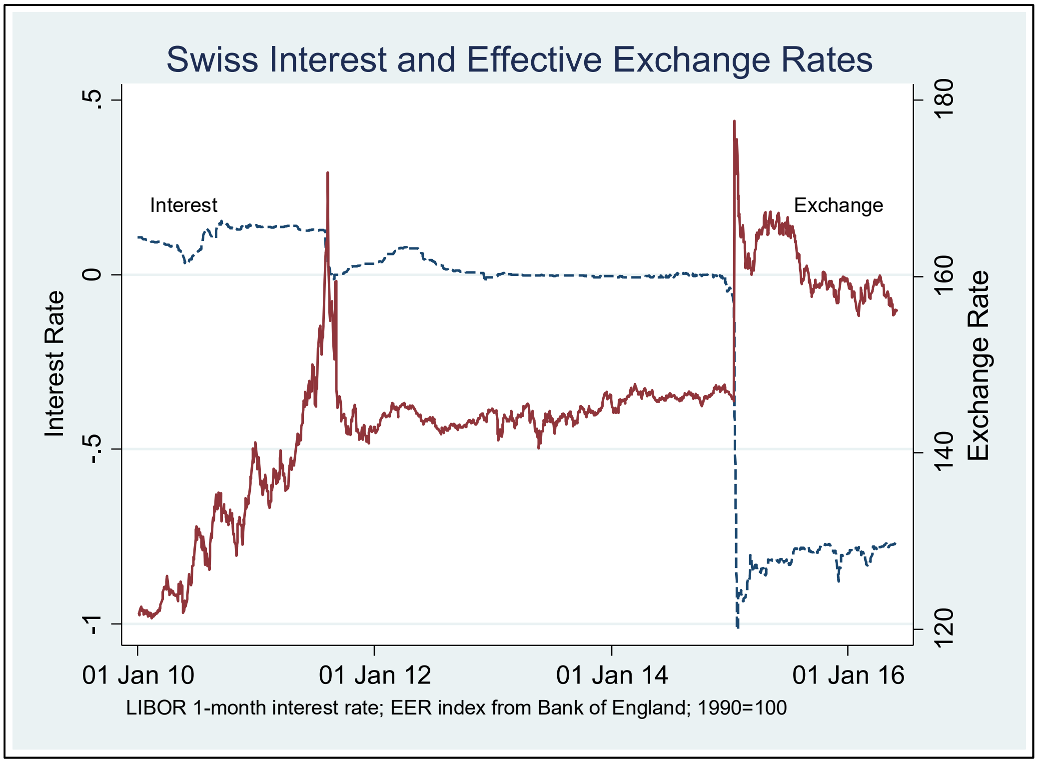

Figure 1

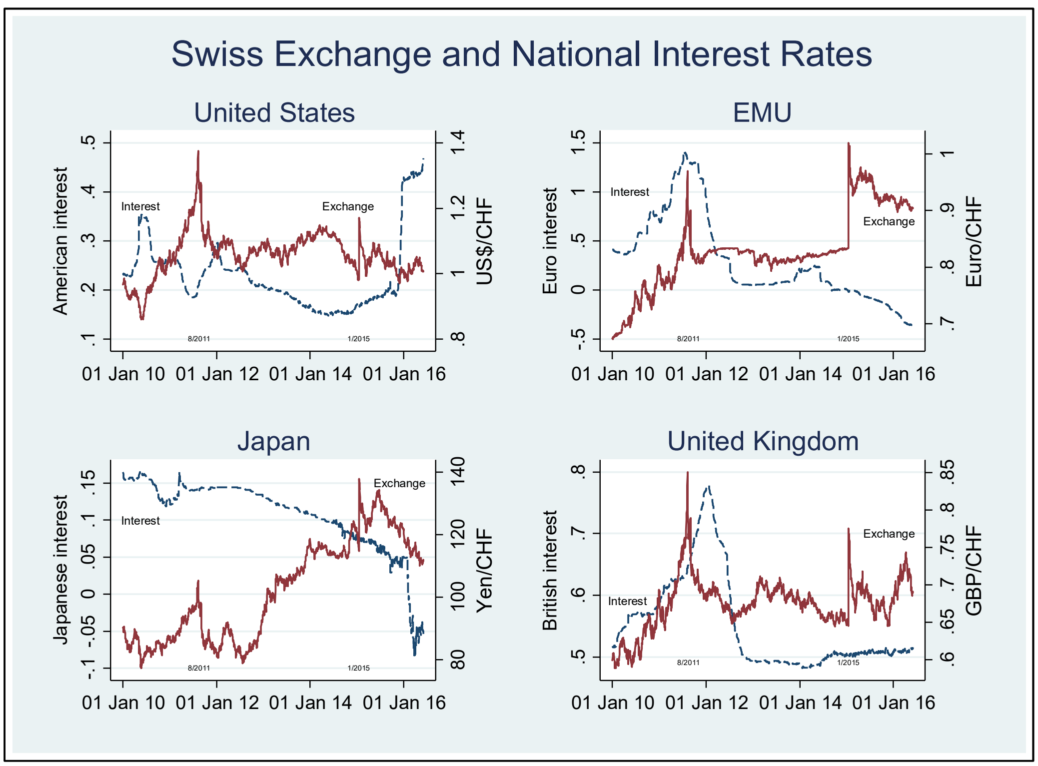

Figure 2

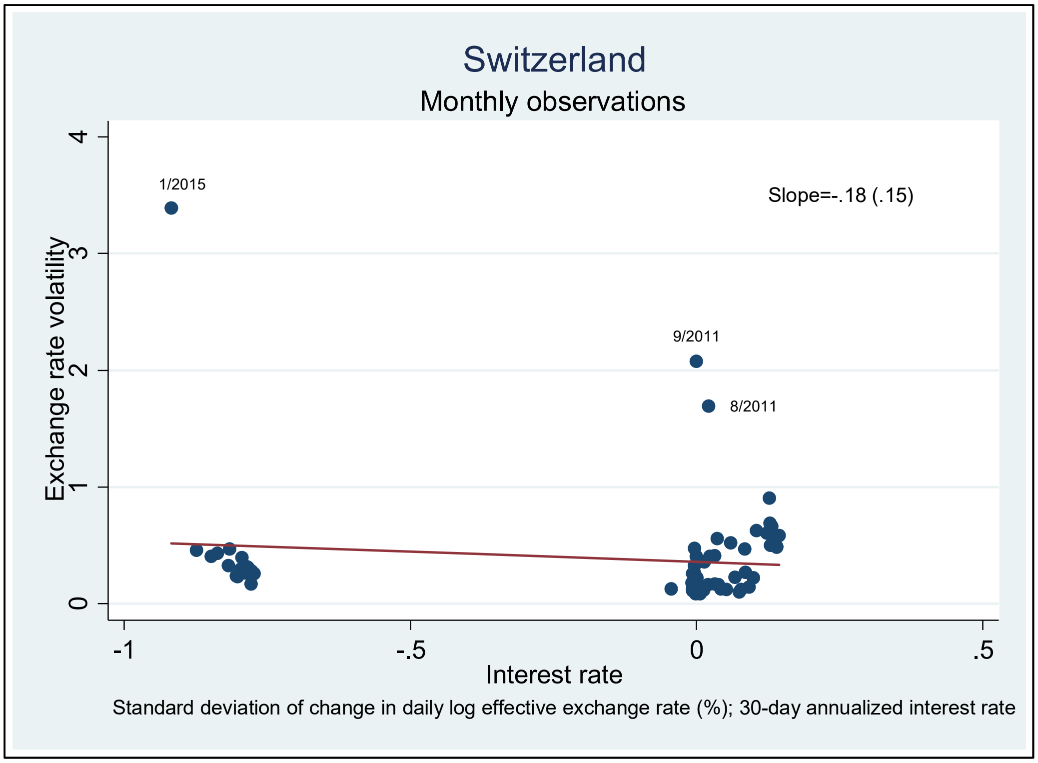

Figure 3

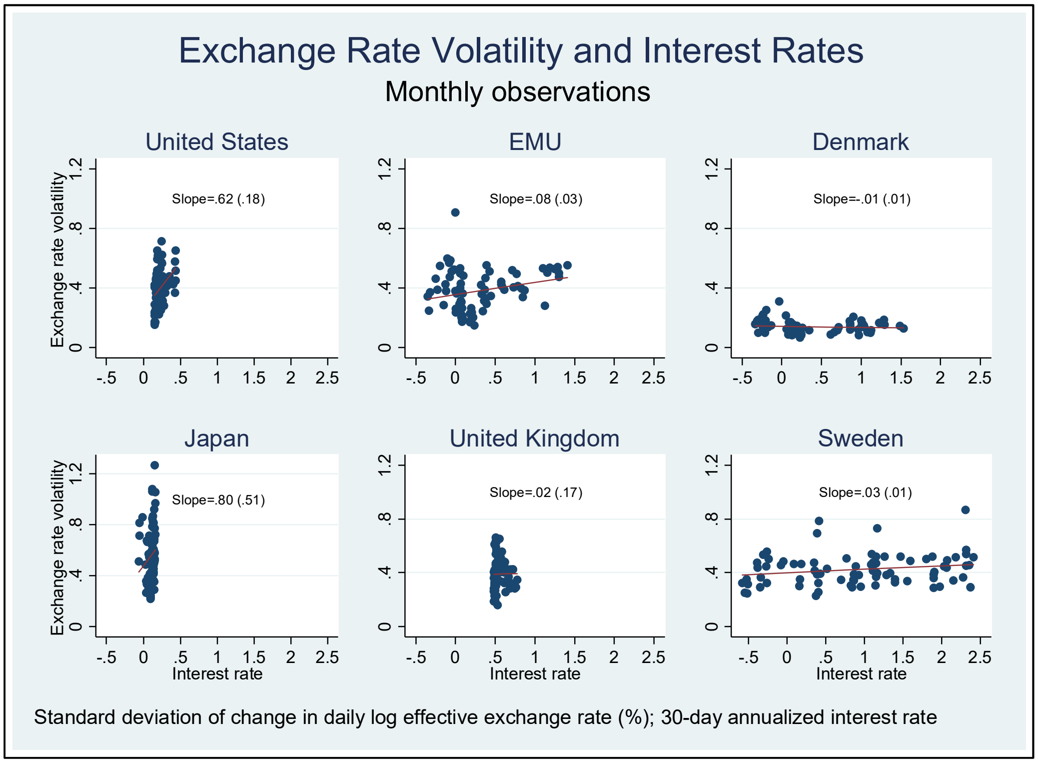

Figure 4

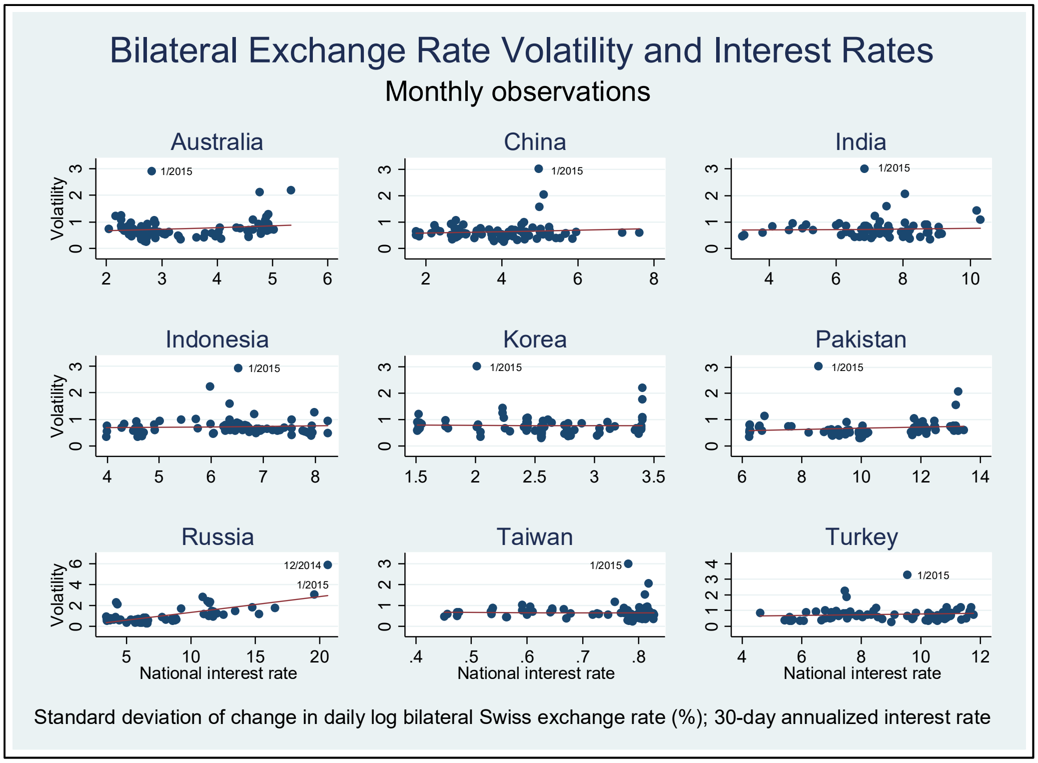

Figure 5

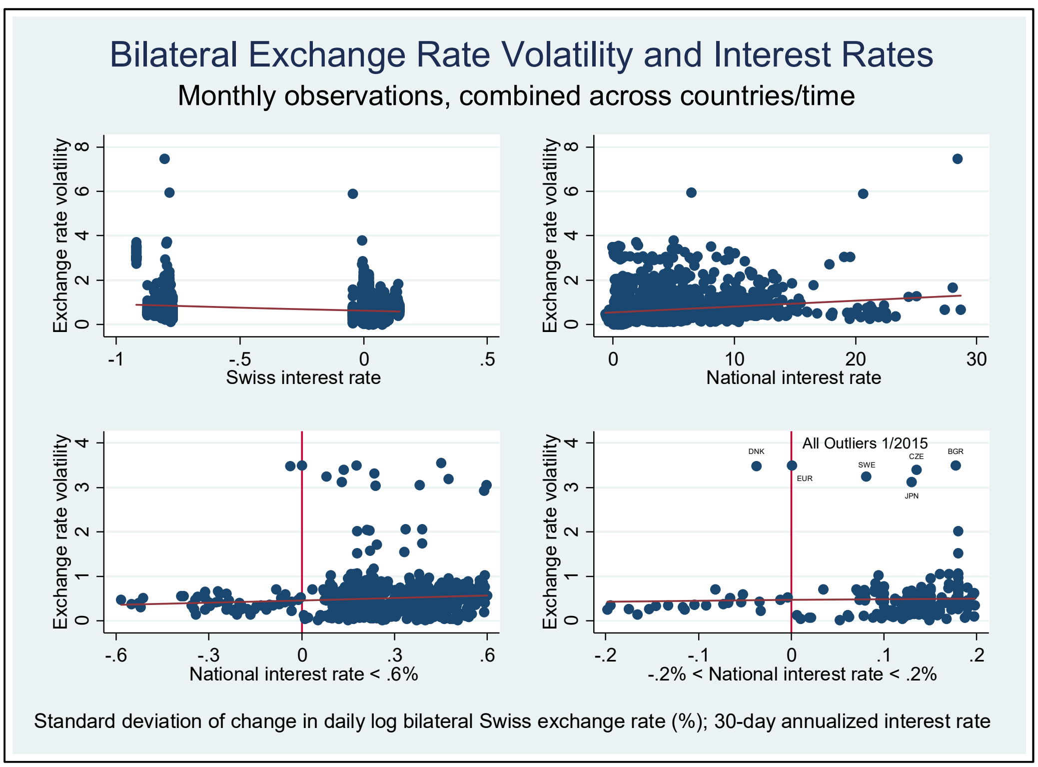

Figure 6

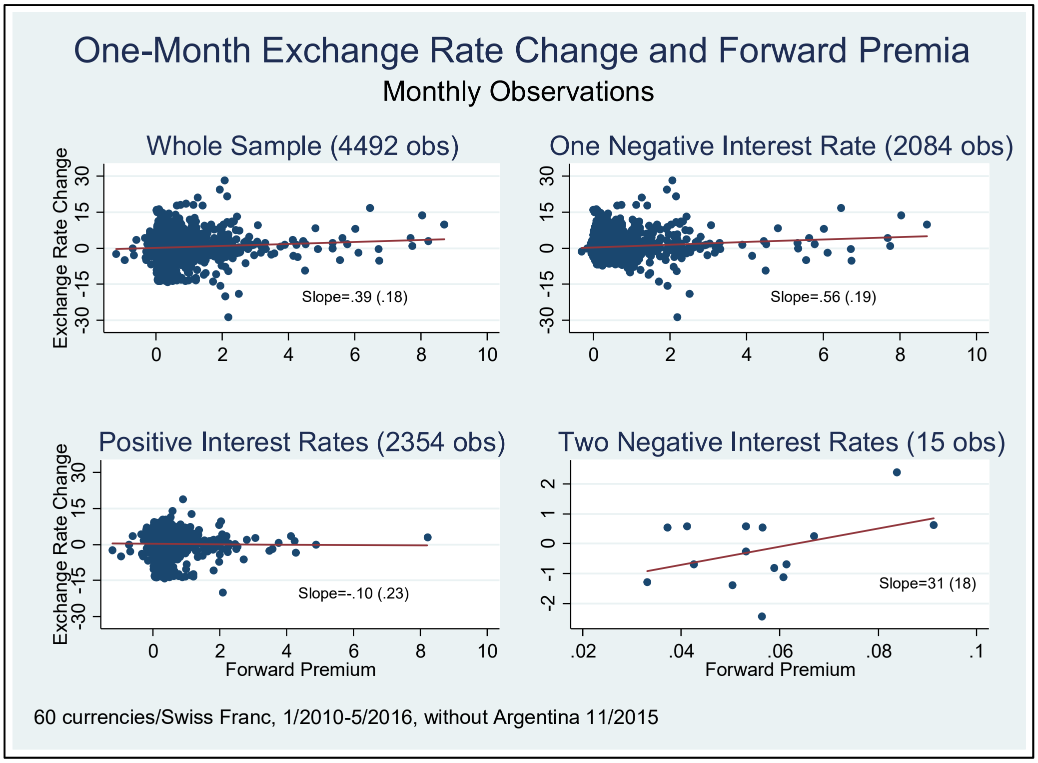

Figure 7

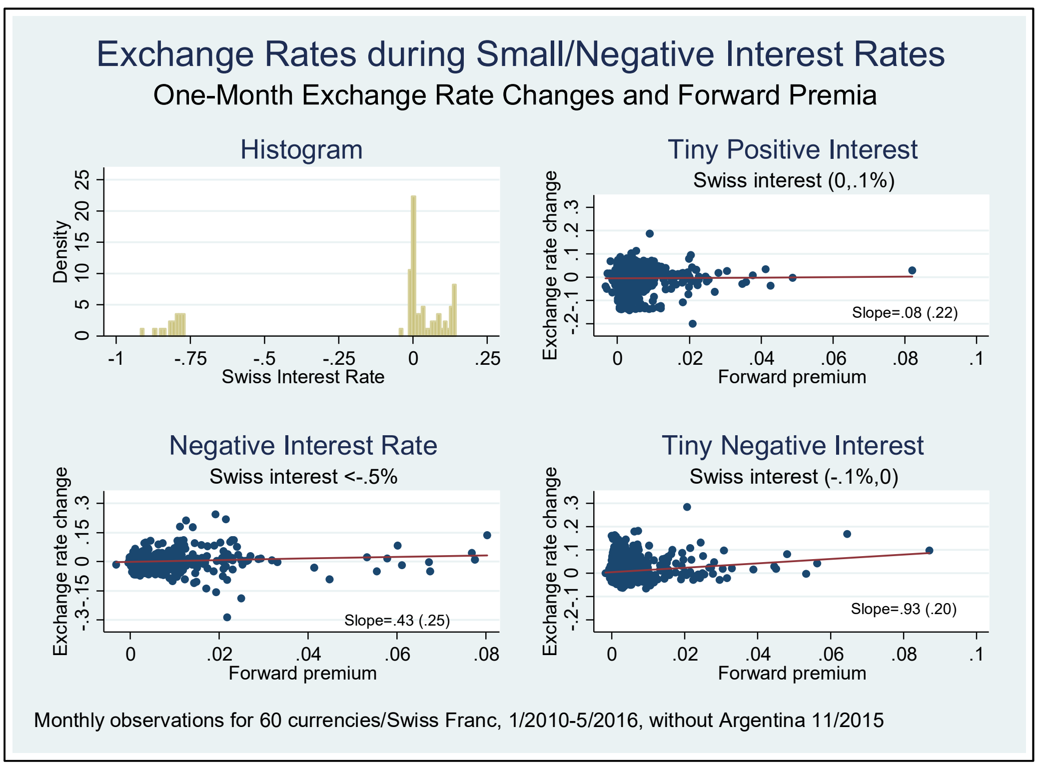

Figure 8

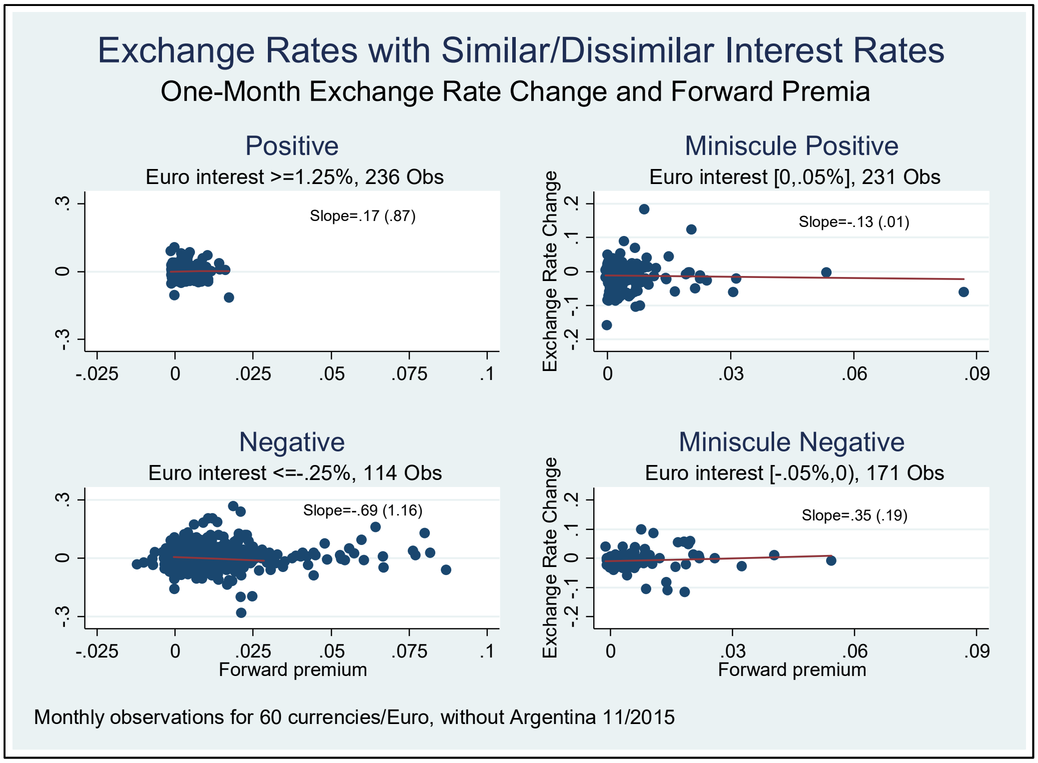

Figure 9

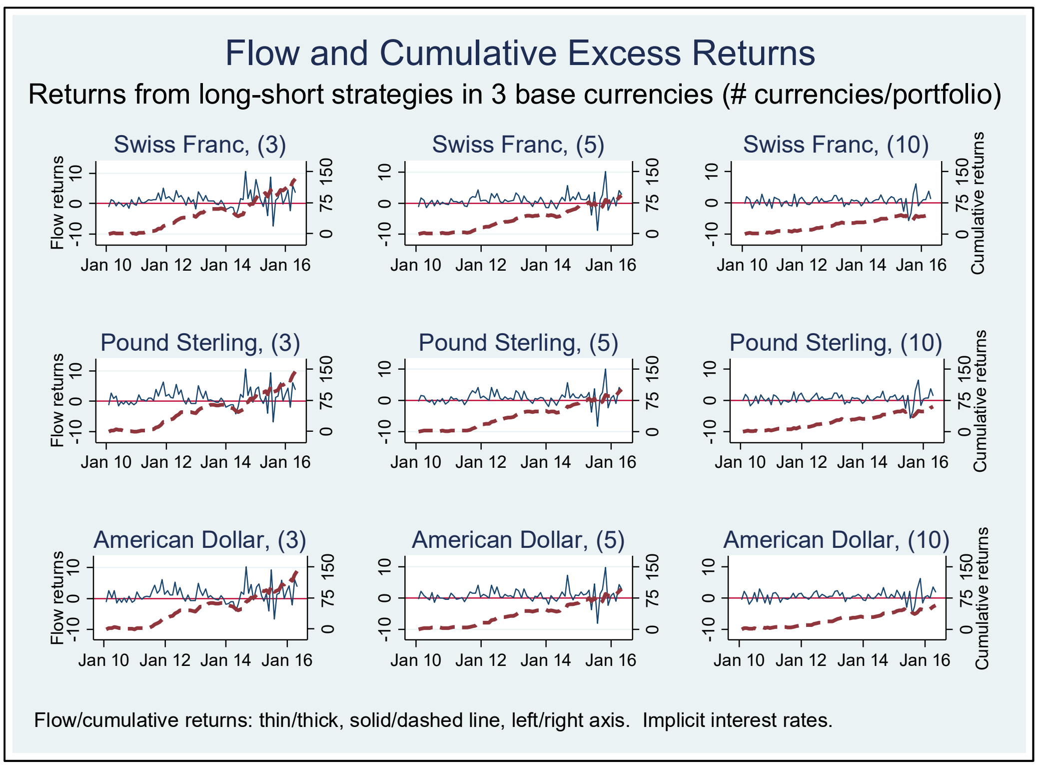

Figure 10

Endnotes

[1] We often refer to these informally below as countries, even though currency unions like the Euro zone include a number of countries.

[2] At least in the relevant sense. In late March 2016, Hungary lowered its overnight deposit rate to -.05%, though the more relevant base rate remained positive and much higher (1.2%).

[3] Again, at least in the relevant sense. Sweden technically had negative interest rates from July 2 2009 through Sept 2 2010, since the (one-week) repo rate was set to .25% and the one-week deposit rate was mechanically cut at that point to -.25%. However, given the small size of the relevant market, this appears to have been a technicality; http://economix.blogs.nytimes.com/2009/10/01/negative-interest-rates-in-sweden/. Sweden ended this period on Sept 2 2010.

[4] During the sample, Switzerland experienced more than twice as many days of negative nominal interest rates as EMU, Denmark and Sweden; Japan has far fewer still.

[5] A number of snapshots are taken from the Reuters system around 16:00hrs and median rates are then selected for each currency. This is done independently for bid and offer quotes. When the rates have been validated WM derive cross rates to GBP and EUR (or GBP and USD). Mid rates are calculated as the arithmetic mean of bid and offer. WM/Reuters monitor national holidays in USA, UK, Germany and Japan, and if two or more of these are open a fixing is produced (if only one is open, generally rates from the previous weekday are used; no fixing is produced on December 25th or January 1st).

[6] These are easily traded assets, and are unlikely to have unusual characteristics of relevance as, for instance, the treasuries discussed in Cecchetti (1988).

[7] The most recent available foreign exchange survey (available from the BIS, http://www.bis.org/publ/rpfxf13fxt.pdf) provides evidence in Table 25, p72, that the top 22 currencies account for all foreign exchange activity in April 2013, or rather essentially all because of rounding error. All these currencies are included, as are the next largest 17 currencies that collectively account for approximately 0% of forex turnover, as well as another 22 currencies with an even small presence.

[8] The BBA LIBOR Fixing is based upon rates supplied by BBA LIBOR contributor panel banks. An individual BBA LIBOR contributor bank contributes the rate at which it could borrow funds, were it to do so by asking for and then accepting inter-bank offers in reasonable market size, just prior to 11:00am London time. Contributor rates are ranked in order and the middle two quartiles averaged arithmetically. Such average rate will be the BBA LIBOR Fixing for that particular currency, maturity and fixing date.

[9] By way of contrast, the other economies experiencing negative nominal interest rates are closer to being free floaters.

[10] One could also imagine using different measures of stochastic volatility or perhaps market-traded currency-related futures measures of volatility such as the EUVIX or JYVIX.

[11] At this frequency, it is difficult to control for "fundamental determinants" of exchange rates that could, in principle, account for some of the volatility. In practice, this is likely to be irrelevant since the profession's knowledge of the determinants of exchange rate volatility is meagre; Rose (2011).

[12] The strongest evidence to the contrary comes from EMU, where the t-statistic for the slope is 2.37, significantly different from zero at the .02 level; the t-statistic for the Swedish slope is 1.78.

[13] Excluding the two outliers marked does not change this result.

[14] It is worth re-emphasizing that observations are dependent across countries at a point in time. This is shown clearly in the bottom-right graph of Figure 6, where all the outliers (labelled by country) are from January 2015.

[15] There is a cluster of observations where exchange rate volatility is high and nominal interest rates are slightly positive, while there is no analogous cluster with slightly negative interest rate. This must be interpreted carefully, since the cluster of

observations are all drawn from the periods at the immediate beginning and end of the Swiss Franc floor. Again: the dependency across observations is a downside of using bilateral data.

[16] While it is typically assumed that CIP works well in practice, Du, Tepper and Verdelhan (2016) provide evidence for persistent recent deviations from CIP.

[17] I also omit an outlier associated with the liberalization of the Argentina exchange rate in December 2015.

[18] The standard errors for Figures 7-9, which combine a variety of bilateral rates, are robust and clustered by time.

[19] The top-left graph portrays data for the *ex post* exchange rate/ forward premium relationship when the Euro interest rate is substantially positive (at least 1.25%); the bottom-left graph is the analogue when the Euro interest rate is -.25% or lower.

[20] The slopes are statistically distinguishable, though only because of the outlier at the extreme right of the graph; dropping that single observation shifts the slope from -.13 (.01) to +.21 (.26).

[21] This is a reasonable starting point since Switzerland had the lowest interest rate for almost all our sample. Still, we provide sensitivity analysis below.