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Thesis Title:

‘An Empirical Analysis of the Uncovered Interest Parity for the Swiss Franc/US dollar Exchange Rate’

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Contents

Acknowledgements

Conducting an empirical analysis is one of the best ways to get to grips with the theoretical material, and to find out what practical difficulties econometricians encounter when conducting research. The present thesis has given me the opportunity to examine closely economics theories using time series methods. By applying modern econometric techniques I have got familiar with econometric tools to problems solving, following the first experience already granted during the courses performed at the Master in Business Administration (M.B.A).

The MBA program has provided me with a diversified knowledge to the various fields of management, compared to my first degree in civil engineering. To this point, I would like to acknowledge the teaching staff of the Business Administration department for the valuable experience and knowledge provided during my studies.

In particular, I would like to express my appreciation to my supervisor professor Costas Karfakis for the inspiring teaching and for the conversations that were being a source of motivation. Also I am grateful for his guidance during the preparation of the thesis.

1. Introduction

The scope of this study is to examine the uncovered interest parity (UIP) for the Swiss franc-US dollar (CHF/USD) exchange rate during the period 1994 -2012. The UIP hypothesis relates the expected exchange rate change to interest rate differential. It should be taken in to account that the Swiss franc is considered a safe haven currency and hence additional particularities are affecting any relationship seeking to explain exchange rate movements. As per RANALDO and SÖDERLIND (2007) the Swiss franc, the yen, and to a limited extent also the euro display safe haven characteristics while the dollar and the pound show no such behavior. In periods of low risk aversion, are usually associated with an appreciation of the US dollar and periods of high risk aversion with a depreciation of the dollar against the yen and the Swiss franc. Similarly, Cairns et al (2007) find that the franc, the euro and to some degree, the yen tend to strengthen against the dollar when volatility rises. However, Cairns et al (2007) also find that the US dollar tends to appreciate during these periods against a number of other currencies, especially those from emerging markets, making it a safe haven relative to them. It seems that a safe haven currency is likely to be buffeted mainly by global factors in times of worldwide turbulence (Hoffmann M. & Suter R., 2009).

2. Literature Review

2.1 General

Since the collapse of Bretton Woods system at early 1970s and the removal from the fixed to fluctuating currency relationships, extended research, with substantial contribution both to the theory and the empirical understanding, of exchange rate determination have been carried out. However many times the findings of these researches are in conflict or questions still remain unanswered. Also the developed models can explain part of the exchange rate movements and to this significantly contributes the specialties of each country currency that is under investigation. A short review of the existing models will follow and afterwards a more relevant literature review for the subject of the thesis will be developed.

One of the most widely studied and still unanswered questions involves why monetary models of exchange rate determination cannot forecast much of the variation in exchange rates. The monetary approach to exchange rate determination was emerged as the dominant exchange rate model at the outset of the float in the early 1970s and remains an important exchange rate model (Mussa, 1976, 1979; Frenkel, 1976; Bilson, 1978). However, Rogoff's (1983a) finding that monetary models forecasts could not outperform a simple no-change forecast was a devastating critique of standard models and marked a watershed in exchange rate economics. Moreover, evidence that monetary models can consistently and significantly outperform a naïve random walk is still elusive (Rapach and Wohar, 2001a,2001b; Faust, Rogers, and Wright, 2001).

The most well known monetary models are the flexible price models (Bilson (1978), Frenkel (1976), Mussa (1976)) and the sticky price models (Dornbusch (1976) and Frankel (1979)). In the flexible price model, the monetary approach starts from the definition of the exchange rate as the relative price of two monies and attempts to model the relative price in terms of the relative supply and demand for those monies (Frenkel, 1976; Mussa, 1976, 1979). As described in Neely Chr. and Sarno L., 2002, another building block of the monetary model is the purchasing power parity (PPP), which holds that goods-market arbitrage will tend to move the exchange rate to equalize prices in two countries. A relative example of the same paper states that if U.S. goods are more expensive than Mexican goods, U.S. and Mexican consumers will tend to purchase more goods in Mexico and fewer in the United States. The increased relative demand for Mexican goods will tend to make the peso appreciate with respect to the dollar and equalize the dollar-denominated prices of U.S. and Mexican goods. Via PPP, the fall in domestic prices (with foreign prices constant) implies an appreciation of the domestic currency in terms of the foreign currency (a rise in the value of domestic currency in terms of foreign currency). The model further assumes that the uncovered interest parity (UIP) condition holds. Also as per Jeffrey A. Frankel (1979) who called the flexible price model as "Chicago" theory, when the domestic interest rate rises relative to the foreign interest rate, it is because the domestic currency is expected to lose value through inflation and depreciation. Demand for the domestic currency falls relative to the foreign currency, which causes it to depreciate instantly. This is a rise in the exchange rate, defined as the price of foreign currency. Thus we get a positive relationship between the exchange rate and the nominal interest differential.

The sticky-price monetary model, originally expressed by Dornbusch (1976), allows short-term overshooting of the nominal and real exchange rates above their long-run equilibrium levels. In this model, it is assumed that there are “jump variables” in the system (exchange rates and interest rates) compensating for stickiness in other variables, notably goods prices. Consider the effects of a cut in the nominal domestic money supply. Since goods prices are sticky in the short run, this implies an initial fall in the real money supply and a consequent rise in interest rates to clear the money market. The rise in domestic interest rates then leads to a capital inflow and an appreciation of the nominal exchange rate. Investors are aware that they are artificially forcing up the value of the domestic currency and that they may therefore suffer a foreign exchange loss when the proceeds of their investment are used to repay liabilities in foreign currency. Nevertheless, as long as the expected foreign exchange loss (the expected rate of depreciation of the domestic currency) is less than the known capital market gain (the interest rate differential), risk-neutral investors will continue to borrow abroad to buy domestic assets. A short-run equilibrium is achieved when the expected rate of depreciation is just equal to the interest rate differential, i.e., when UIP holds. Since the domestic currency must be expected to depreciate because of the interest rate differential, the domestic currency must have appreciated beyond its long-run, PPP equilibrium. In the medium run, however, domestic prices begin to fall in response to the fall in the money supply. This alleviates pressure in the money market (the real money supply rises), and domestic interest rates start to decline. The exchange rate then depreciates slowly toward long-run PPP. Thus, this model can explain the apparent paradox that the currencies of countries with relatively higher interest rates tend to depreciate: the initial rise in the interest rate induces a sharp exchange rate appreciation, followed by a slow depreciation as prices adjust, which continues until long-run PPP is satisfied. The sticky-price monetary model as per Jeffrey A. Frankel (1979) is also called "Keynesian" theory. According to him the “Chicago” theory is a realistic description when variation in the inflation differential is large and the “Keynesian” theory is a realistic description when variation in the inflation differential is small.

2.2 Uncovered Interest Parity (UIP)

The UIP hypothesis states that the gains due to interest-rate differentials (IRDs) are offset by the loss arising in the depreciation of the target currency. However, several empirical studies emphasize the violation of UIP like Meese and Rogoff (1983) research who compared the out-of-sample forecast accuracy of different structural exchange rate models and concluded that exchange rates follow a "near random walk". More specifically, Fama (1984) shows that on average the target currency appreciates. This empirical anomaly of the foreign exchange market makes carry trade profitable on average. 'Carry trade' refers to the situation, in which investors borrow in markets where interest rates are low and then exchange the local currency to invest in markets where rates are higher.

Due to the close relation of UIP and the carry trade, extended research has been performed in order to explain the behavior of these movements. Brunnermeier et al. (2009) show that in times of reduced funding liquidity and declining risk appetite carry traders are subject to crash risk due to the sudden unwinding of carry trades. Nishigaki (2007) examines the yen carry trade. The results show USD depreciation against the Japanese yen once carry trades unwind. The same occurred during the recent financial crisis of 2008. As the credit crunch hit and uncertainty rose many of these traders were unwound leading to a strong rally in the Swiss Franc. Afterwards the problems came in the periphery of the Euro zone which made nearby safe Switzerland look a haven and so yet more upward pressure was applied to the Swiss Franc.

Also some analyses of the IRD indicate a nonlinear relationship among the variables as shown in the findings of Tsay (1998) test that confirms the assumption of nonlinearity. In a recent study of Matthias Gubler (2012) is shown that in line with the prediction of UIP, the CHF appreciates instantaneously against the USD in times with high IRDs, but not in the regime with low IRDs. This instantaneous reaction of the exchange rate CHF/USD against IRDs is also valid for the current study. Hattori & Shin (2007) by using descriptive statistics and a simple econometrics analysis, they reveal a positive relationship between the IRD and carry trades. Clarida et al. (2009) examine carry trade strategies and identify a robust empirical relationship between their excess returns and exchange rate volatility. Furthermore, they show that the failure of the UIP is only present in low-volatility environments.

Moreover, the notion that departures from uncovered interest parity could be driven by currency risk premia was viewed with considerable skepticism by many in the economics profession (Engel, 1996). The seminal work by Lustig and Verdelhan (2007) has helped to initiate a gradual change of this view. Lustig and Verdelhan argue that excess returns on currency portfolios that are formed on the size of the interest rate differential towards the US dollar can be explained by a version of the consumption-based capital asset pricing model. In more recent work, Lustig, Roussanov and Verdelhan (2009) propose a linear factor model in which the spread between the return on the highest and lowest interest rate portfolios – a global carry trade factor – helps explain a significant share in the cross-sectional variation of currency returns. Similar to Lustig, Roussanov and Verdelhan (2009), Hoffmann M. and Suter R. (2009), argue that cross-country differences in the exposure to the global factor can help explain differences in the size of the departure from uncovered interest parity (UIP).

As shown by Bekaert G, Wei M and Xing Y 2007, UIP is one of the cornerstones of international finance, constituting an important building block of the most important exchange rate determination theories such as the monetary exchange rate model, Dornbusch's (1976) overshooting model or Krugman's (1991) target zone model and dominating the discussion on exchange rate determination in most international textbooks. However there is empirical evidence against UIP, at least at frequencies less than 1 year (Bekaert and Hodrick, 1993; Engel, 1996; Froot and Thaler, 1990; Mark and Wu, 1998). Although this empirical evidence, theorists have not stopped relying on UIP. Some recent UIP evidence is more favorable: Bekaert and Hodrick (2001) and Baillie and Bollerslev (2000) argue that doubtful statistical inference may have contributed to the strong rejections of UIP at higher frequencies whereas Chinn and Meredith (2004) have strong evidence that UIP holds much better at long horizons. Chaboud and Wright (2005) investigate overnight exchange rate movements and interest-rate differentials and also find support for UIP. Short-term deviations of UIP may occur while long-horizon UIP holds (Froot and Thaler, 1990), if inefficient markets or short-term market frictions prevent an immediate complete response of the exchange rate to an interest rate change. However, both the theoretical and the empirical results seem puzzling on second thought. As Bekaert G, Wei M and Xing Y 2007 say, it is hard to reconcile the high frequency Chaboud and Wright (2005) results, the standard rejections at weekly or monthly frequencies and the long-term evidence from this frictions perspective. In fact, the presence of speculative capital of various proprietary desks in foreign exchange markets attempting to exploit deviations from UIP (Green, 1992) suggests that it might be the long-term relation rather than the short-term relation that is affected by market frictions, since it is unlikely that these trading desks will keep capital tied up in such long-term contracts. Also, if UIP holds in the short run, it should hold in the long run as long as the expectations hypotheses of the term structure of interest rates (EHTS) holds. It seems unlikely that the short-term deviations from UIP would exactly offset the long-term deviations from the EHTS to make UIP hold in the long run. In alternative models based on risk, a time-varying risk premium separates expected exchange rate changes from the interest differential and a time-varying term premium separates the long-term interest rate from expected future short rates. Consequently, these risk premiums would be driven by the same fundamentals and deviations from UIP and the EHTS should be visible at both long and short horizons (Bekaert G, Wei M and Xing Y 2007). This is potentially consistent with the Chaboud and Wright (2005) results as they focus on observations where exchange risk is minimal and the risk premium may vanish.

Furthermore as pointed out in Chinn and Meredith (2004), one notable aspect of almost all published studies is that the unbiasedness hypothesis has been tested using financial instruments with relatively short maturities, generally of 12 months or less. In Chinn and Meredith (2005), it is found evidence that the perverse relationship between interest rates and exchange rates is a feature of the short-horizon data. When using longer horizon data, the standard test of UIP yields strikingly different results, with slope parameters that are positive and insignificantly different from the value of unity. These results hold up against a number of robustness checks, and support the conjectures of Mussa (1979) and Froot and Thaler (1990) that the unbiasedness proposition may better apply at longer horizons.

In the light of the above mentioned literature, it is easily understood that seems rather difficult to find a coherent story to explain all these results. Especially for Switzerland, safe haven arguments should be considered before any effort to explain the movements of the exchange rate or the predictability of the forward rate. Switzerland include banking secrecy laws, good quality of banking services, high stability of the financial system, or more generally, regulations that are friendly to investors. According to these arguments, investors are prepared to accept lower yields in return for some special benefits available only in Switzerland. The tax haven is a close relative of the more general safe haven arguments. The argument is that high capital inflows, lower interest rates since foreign investors are willing to pay a premium for holding assets in Switzerland. Investors may be prepared to accept lower returns over long periods if they expected the Swiss Franc to appreciate in times of unexpected political turmoil in other countries. Under these acceptances any observed departure from UIP could be interpreted as an insurance premium (or a currency risk bonus) against certain events.

3. Analytical Framework & Data

According to UIP hypothesis, the expected exchange rate changes are related to interest rate differential. Since we are interested in accounting for interest rate dynamics, we write the UIP hypothesis as follows:

$$E(e_{t+1}) - e_t = a + bIRDt + cIRDt\text{-}1 + \ldots + kIRDt\text{-}n + u_t \quad (1)$$

where *IRD* is the Interest Rate Differential of the two countries, that is, $IRD = r\text{-}r^*$, n is the lag of *IRD* (the value that the variable took during a previous period) and u_t is the error term. The stochastic error term is a catchall that includes all the variables that cannot be readily quantified. It may represent variables that cannot be included in the model for lack of data availability or errors of measurement in the data or intrinsic randomness in human behavior.

The theoretical restrictions imply that a=0 & the sum of all lagged values of IRD is negative and statistically significant.

Regarding the interest rates, the current study considers the three-month Libor that consist an operational goal in the form of a target range for the Swiss National Bank (SNB) during the exercise of its monetary policy strategy. This base rate is also called the reference interest rate and is used by the Swiss central bank to guide the level of interest rates in the Swiss money market. The SNB does that, by setting a goal for the 3 month Libor rate, the 'SNB target range'. The Swiss central bank sets both a lower and upper limit and a target within that range. The lower and upper limit is usually around 1 percentage point apart and generally speaking the target is in the middle of the range. The SNB can thus use its monetary policy to influence the interest rates for products such as loans, savings and mortgages.

The London Interbank Offered Rate (LIBOR) is an interest rate based on the average interest rates at which a large number of international banks in London lend money to one another. The official Libor rates are calculated on a daily basis and made public at 11:00 (London Time) by the British Bankers' Association (BBA). The daily reported interest rates are the mean of the middle values. The rates are a benchmark rather than a tradable rate and the actual rate at which banks will lend to one another continues to vary throughout the day. The Libor rates come in different maturities and different currencies. The Swiss franc Libor rates can be considered as the interbank cost of borrowing funds in Swiss francs and the US dollar Libor rates can be considered as the interbank cost of borrowing funds in US dollars.

All Time Series data have been collected from Federal Reserve Economic Data (FRED) base. Frequency of data used is quarterly for the period, from 1994:Q1 to 2012:Q2. As already mentioned the 3 month Libor is employed as the representative interest rate for both Swiss franc and US dollar. The spot exchange rate is considered as Swiss francs per US dollars (CHF/USD).

For the purpose of estimation, it is employed the following operational counterparts to the variables used in equation (1).

- **l_SCHFUSD:** the log of the CHF/USD spot exchange rate, expressed as the number of Swiss francs per US dollars; Aggregation method used, is on average; Series ID is EXSZUS and origin source the Board of Governors of the Federal Reserve System;
- **d_l_SCHFUSD:** First difference of l_SCHFUSD.
- **SW3ML:** the 3-Month London Interbank Offered Rate (LIBOR), based on Swiss Franc; Units in percent; Series ID is CHF3MTD156N and origin source the British Bankers' Association.
- **US3ML:** 3-Month London Interbank Offered Rate (LIBOR), based on U.S. Dollar; Units in percent; Series ID is USD3MTD156N and origin source the British Bankers' Association.

- **LM3_dif:** the Swiss franc 3 month Libor minus the US dollar 3 month Libor, that is, SW3ML – US3ML.

4. Empirical Analysis

4.1. UIP: 1994:01-2008:4

Before proceeding with the OLS analysis, it is important to establish the order of integration of the series to be used. The time series to be used are the exchange rate CHF/USD against the interest rate differential for the sample period 1994:1 - 2008:4. In regression analysis involving time series data, a critical assumption is that the time series under consideration is stationary. Broadly speaking, a time series is stationary if its mean and variance are constant over time and the value of covariance between two time periods depends only on the distance or gap between the two periods and not the actual time at which the covariance is computed.

A look at figure 1 suggests that for the examined time period (1994:1 – 2008:4), the first difference of exchange rate (d_l_SCHFUSD) is stationary. The same could be said for the interest rate differential (LM3_dif) of the two countries. Of course, it won't be the same in the case we consider a sub-period of 1994:1-2008:4. Then, the LM3_dif will drift upward or downward, depending on the selected period and neither the mean nor the variance will be stationary.

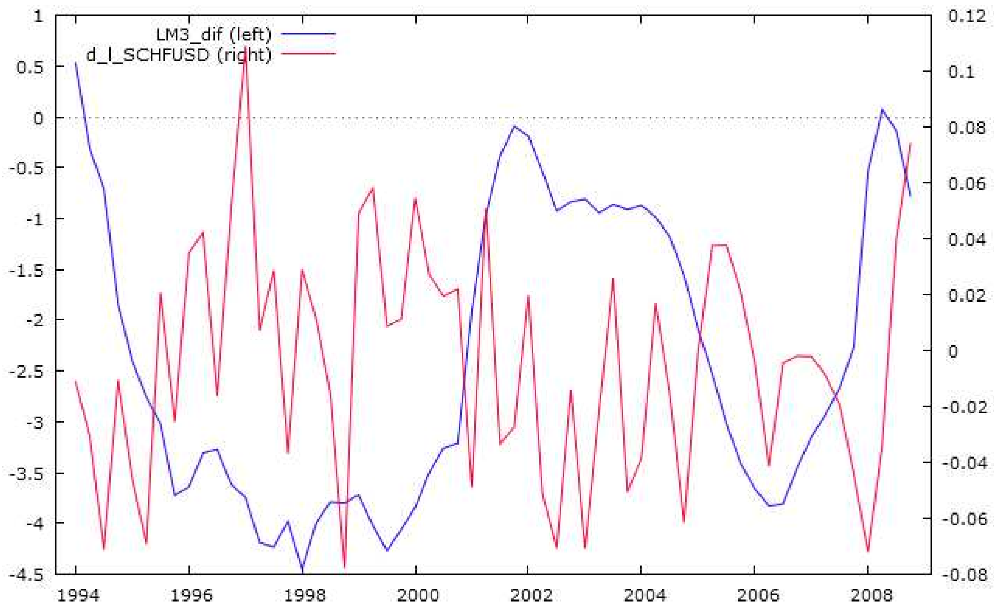

Figure 1. CHF/USD change (d_l_SCHFUSD) and Interest Rate Differential (LM3_dif)

However the graphical analysis is a rough method for testing the stationarity. The stationarity of both time series should be tested with a more formal test. Unit-root test for the levels of the series for the sample period are reported in table 1. The augmented Dickey-Fuller (ADF) test is considered for checking the stationarity of both series.

Table 1. Unit-Root Tests (Augmented Dickey-Fuller_ADF)

Variable	ADF without trend (p-value)	ADF with trend (p-value)	Time p-value
d_l_SCHFUSD	-5.73092 (8.123e-006)***	-5.67327 (7.886e-005)***	0.8155
LM3_dif	-2.88492 (0.04711)**	-3.0864 0.1095	0.1642

Note: The full ADF tests of both variables are depicted in the Annex.

The ADF tests reject the null hypothesis of a unit root in the levels of the series at the 1% and 5% significance level for the d_l_SCHFUSD and LM3_dif respectively, that is, both series are stationary I(0).

There are several reasons why the concept of non-stationarity is important and why it is essential that variables that are non-stationary be treated differently from those that are stationary. First, if a time series is nonstationary, we can study its behavior only for the period under consideration. Each time series will therefore be a particular episode. As a result, it will not be possible to generalize it to other time periods. For forecasting purposes, therefore, nonstationary time series will be of little practical value. Second, the use of non-stationary data can lead to spurious regressions. If two stationary variables are generated as independent random series, when one of those variables is regressed on the other, the *t*-ratio on the slope coefficient would be expected not to be significantly different from zero, and the value of R^2 would be expected to be very low. This seems obvious, for the variables that are not related to one another. However, if two variables are trending over time, a regression of one on the other could have a high R^2 even if the two are totally unrelated. So, if standard regression techniques are applied to non-stationary data, the end result could be a regression that 'looks' good under standard measures (significant estimated coefficients and a high R^2), but which is really valueless. Such a model would be termed a 'spurious regression'. If the variables employed in a regression model are not stationary, then it can be proved that the standard assumptions for asymptotic analysis will not be valid. In other words, the usual '*t*-ratios' will not follow a *t*-distribution, and the *F*-statistic will not follow an *F*-distribution. Hence in cases of nonstationary time series, these tests are not reliable.

OLS Analysis

Since both series are I(0), the ordinary least squares (OLS) method will be used to estimate the regression coefficients of the equation (1).

A VAR model should also be used in order to capture any long-run relationship among the two variables (*d_l_SCHFUSD, LM3_dif).* Vector autoregressive models (VARs) were popularized in econometrics by Sims (1980). VARs have often been advocated as an alternative to large-scale simultaneous equations structural models. VAR models have several advantages compared with univariate time series models or simultaneous equations structural models:

a. The researcher does not need to specify which variables are endogenous or exogenous -- *all are endogenous*. This is a very important point, since a requirement for simultaneous equations structural models to be estimable is that all equations in the system are identified.

b. VARs allow the value of a variable to depend on more than just its own lags or combinations of white noise terms.

c. Provided that there are no contemporaneous terms on the RHS (right hand side) of the equations, it is possible to simply use OLS separately on each equation. This arises from the fact that all variables on the RHS are pre-determined, that is, at time *t*, they are known. This implies that there is no possibility for feedback from any of the LHS variables to any of the RHS variables. Pre-determined variables include all exogenous variables and lagged values of the endogenous variables.

However before proceeding with the OLS method, it is essential to select the optimum lag for the VAR using the information criteria (Akaike, Schwarz and Hanna-Quinn). The three criteria indicate that two lags are optimal for the system as shown in table 2.

Table 2. The asterisks below indicate the best (that is, minimized) values of the respective information criteria, AIC = Akaike criterion, BIC = Schwarz Bayesian criterion and HQC = Hannan-Quinn criterion.

lags	loglik	p(LR)	AIC	BIC	HQC
2	109.58673	0.00000	-2.691533*	-2.380173*	-2.567328*

Note: The full information criteria test is depicted in the Annex.

As explained in the c. characteristic of VAR models, it is possible to use OLS in case that there are no contemporaneous terms. However equation (1) contains the contemporaneous term of L3M-dif when the depended variable is the d_l_SCHFUSD. Althought it is not in line with the VAR preconditions, we can still apply OLS as we already know from UIP theory that the IRDs variable is the one that affects the exchange rate and not the opposite. So, the coefficient of the contemporaneous affect of the variable d_l_SCHFUSD to the L3M-dif could be considered as zero. Simply speaking, in case it is possible from theory to consider a22 = 0 in the below two equations system, then we could apply the OLS method.

$$y_{1t} = \beta_{10} + \beta_{11} y_{1t-1} + \alpha_{11} y_{2t-1} + \alpha_{12} y_{2t} + u_{1t}$$
$$y_{2t} = \beta_{20} + \beta_{21} y_{2t-1} + \alpha_{21} y_{1t-1} + \alpha_{22} y_{1t} + u_{2t}$$

This procedure, looking for an ordering of the variables in terms of contemporaneous causality is one way of solving the identification problem (it was advanced by Sims (1980)). There are other identification techniques that have also been suggested and are used by various researchers, but all require putting restrictions on the coefficients - and so all end up being not completely agnostic about theory - i.e., we need to appeal to theory at least to some degree to determine if any recursive ordering (or more generally, any set of identifying restrictions) makes theoretical sense.

Thus, we apply OLS (with lag order equal to 2) in order to estimate the regression coefficients of the equation (1), for the time period 1994:1 – 2008:4. The results are shown in table 3&4.

Table 3.

OLS, using observations 1994:1-2008:4 (T = 60)					
Dependent variable: d_l_SCHFUSD					
HAC standard errors, bandwidth 2 (Bartlett kernel)					
	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	-0.030907	0.00806897	-3.8304	0.00033	***
LM3_dif	-0.0324753	0.0103932	-3.1247	0.00282	***
LM3_dif_1	0.0438805	0.0190673	2.3013	0.02512	**
LM3_dif_2	-0.0227444	0.0120747	-1.8836	0.06481	*

Mean dependent var	-0.003978	S.D. dependent var	0.041501
Sum squared resid	0.083846	S.E. of regression	0.038694
R-squared	0.174903	Adjusted R-squared	0.130702
F(3, 56)	7.379018	P-value(F)	0.000299
Log-likelihood	112.0573	Akaike criterion	-216.1146
Schwarz criterion	-207.7372	Hannan-Quinn	-212.8377
rho	0.047076	Durbin-Watson	1.816603

Note: The full table is depicted in the Annex.

Following that, we estimate the role of the sum of coefficients from the lagged variables LM3_dif_1 LM3_dif_2, to the dependent variable and the result is the following.

Table 4. Sum of coefficients from variables: LM3_dif_1 LM3_dif_2

Sum of coefficients	Standard error	t(56) = 1.99914
(0.0211361)	0.0105726	p-value = 0.0504547

Note: The full table is depicted in the Annex.

Explanation of Results

We notice that indeed there is a relationship between the exchange rate movements and the interest rate differentials of the two countries with statistical significant slope coefficients. Also, the signs of all parameters are in the correct sign. The slope coefficient (-0.03) of the contemporaneous term suggests that 1% increase in the Interest Rate Differential (domestic minus foreign interest rate) of 3month Libor, leads down the exchange rate CHF per USD by about 3%, ceteris paribus. It means that the CHF appreciates instantaneously against the USD because of capital inflows that want to take advantage of higher interest rates. However later in time, the investors will switch the funds back in USA causing depreciation of the Swiss Franc and this is shown by the positive sum of the lagged values of IRD.

Summarizing, we find that,

1) the relationship between the change in the exchange rate and the sum of the lagged values of IRD is positive and statistically significant, indicating that an increase in IRD will depreciate the exchange rate (CHF), something which accords with the theory, and

2) the contemporaneous relationship is negative, showing that an increase in IRD will appreciate the exchange rate (CHF).

CUSUMSQ TEST

In order to study the stability of the parameters of equation (1), a recursive test will be performed. Recursive estimation simply involves starting with a subsample of the data, estimating the regression, then sequentially adding one observation at a time and re-running the regression until the end of the sample is reached. It is common to begin the initial estimation with the very minimum number of observations possible, which will be $k + 1$. So at the first step, the model is estimated using observations 1 to $k + 1$; at the second step, observations 1 to $k + 2$ are used and so on; at the final step, observations 1 to T are used. The final result will be the production of $T - k$ separate estimates of every parameter in the regression model. It is to be expected that the parameter estimates produced close the start of the recursive procedure will appear rather unstable since these estimates are being produced using so few observations, but the key question is whether they then gradually settle down or whether the volatility continues through the whole sample. Seeing the latter would be an indication of parameter instability. Two important stability tests, known as the *CUSUM* and *CUSUMSQ* tests, are derived from the residuals of the recursive estimation.

The CUSUMSQ test is based on a normalised version of the cumulative sums of squared residuals. The scaling is such that under the null hypothesis of parameter stability, the CUSUMSQ statistic will start at zero and end the sample with a value of 1. Again, a set of ±2 standard error bands is usually plotted around zero and any statistic lying outside these is taken as evidence of parameter instability.

By performing the CUSUMSQ test on model (1) we receive the results shown in figure 2.

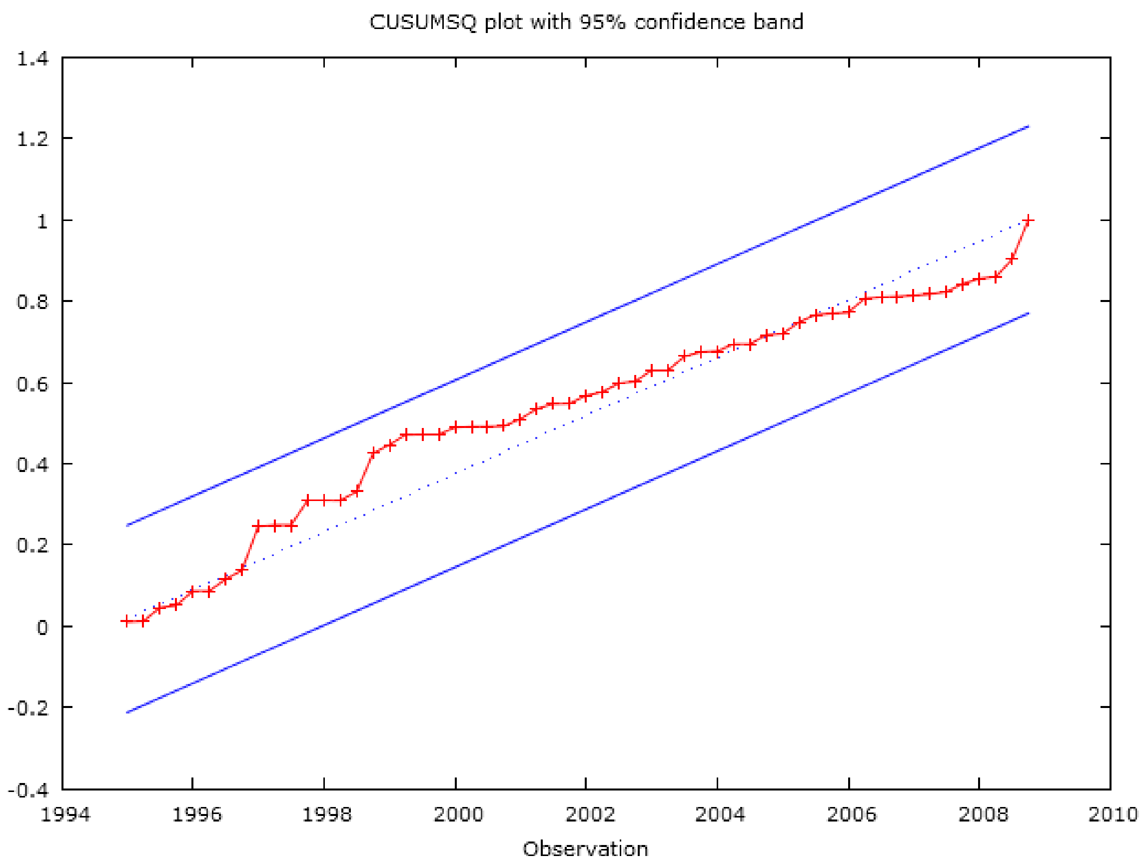

Figure 2. CUSUMSQ test

Looking at figure 2, we see that the red line is well within the confidence bands, evidence for parameter stability.

4.2. UIP: 1994:01-2012:2

In order to increase our sample we will try to run the same regression until the recent time. Including all the observations in one regression we increase the degrees of freedom and it may improve the relative precision of the estimated parameters. So, the new sample period will be from 1994:1 until 2012:2. Figure 3, presents the time series plot of both variables. A look at the figure suggests that a change occurred in the behavior of the LM3_dif close to 2008 year. It is observed that IRDs between the two countries are very small and close to zero. This is also reinforced by figure 4, where at the mentioned period (close to 2008 until 2012:2) both Switzerland and USA dropped the interest rates and maintained them close to zero.

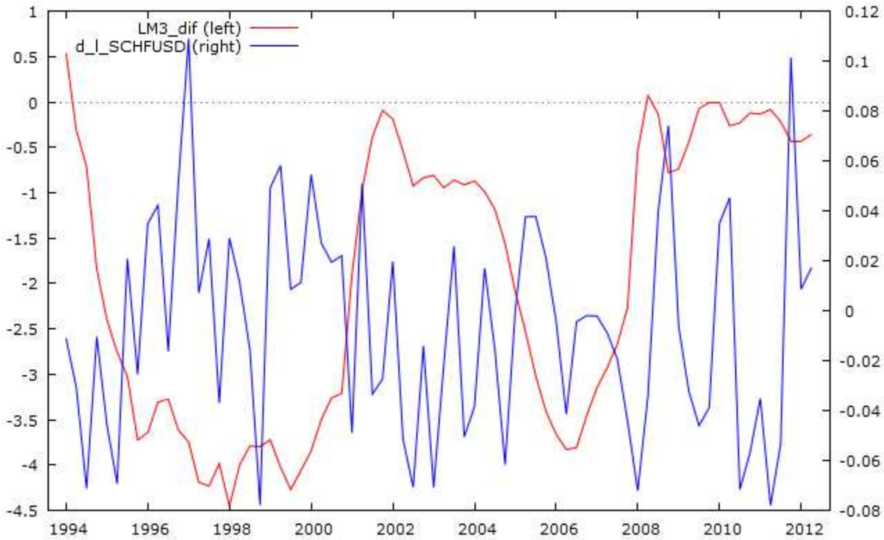

Figure 3. CHF/USD change (d_l_SCHFUSD) and Interest Rate Differential (LM3_dif)

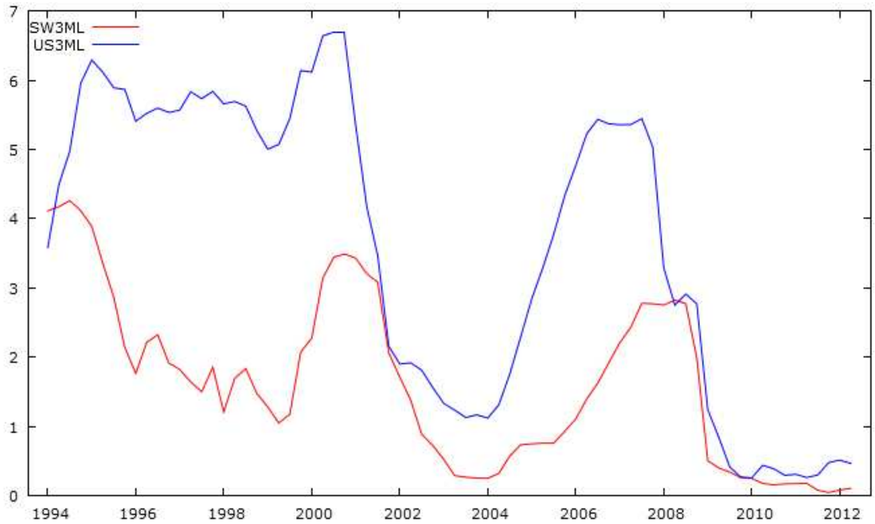

Figure 4. Swiss and US Interest Rates

It is quite likely that the exchange rate – IRD relationship postulated in equation (1) may have gone a structural change since 2008. It is the period where the financial crisis in USA flared up, affecting the global economy with consequences that are still holding. One of the reactions in the policy of Central Banks was to drop the interest rates in an effort to avoid recession. To see if in fact the US and Swiss economy have undergone a structural change, we can use either dummy variables or perform the Chow and QLR (*Quandt likelihood ratio)* test to shed light to this.

Before we do that, let's check the time series stationarity. Unit-root test for the levels of the series for the sample period are reported in table 5.

Table 5. Unit-Root Tests (Augmented Dickey-Fuller_ADF)

Variable	ADF without trend (p-value)	ADF with trend (p-value)	Time p-value
d_l_SCHFUSD	-6.75079 (3.181e-007)***	-6.75003 (1.38e-006)***	0.5350
LM3_dif	-2.43561 0.1319	-3.39599 0.05184*	0.0134 **

Note: The full ADF tests of both variables are depicted in the Annex.

The ADF test rejects the null hypothesis of a unit root in the level of the series at the 1% for the d_l_SCHFUSD without trend, that is, d_l_SCHFUSD is I(0). Regarding the LM3_dif, the stationarity is not so strong. However observing figure 3, the variable LM3_dif seems to be stationary without trend, for the whole sample period with a small break around 2008. As per Chris Brooks (2008), it is widely known that the power of unit root tests is low in the presence of structural breaks, as the ADF test finds it difficult to distinguish between a stationary process subject to structural breaks and a unit root process.

The Chow and the QLR (*Quandt likelihood ratio)* test

When we use a regression model involving time series data, it may happen that there is a **structural change** in the relationship between the regressand *Y* and the regressors. By structural change, we mean that the values of the parameters of the model do not remain the same through the entire time period, that is, the intercept and the slope coefficients are different. The classical test for structural change is typically attributed to Chow (1960). His famous testing procedure splits the sample into two subperiods, estimates the parameters for each sub period, and then tests the equality of the two sets of parameters using a classic *F* statistic. This test was popular for many years and was extended to cover most econometric models of interest. However, an important limitation of the Chow test is that the break date must be known a priori. A researcher has only two choices: to pick an arbitrary candidate break date or to pick a break date based on some known feature of the data. In the first case, the Chow test may be uninformative, as the true break date can be missed. In the second case, the Chow test can be misleading, as the candidate break date is endogenous—it is correlated with the data—and the test is likely to indicate a break falsely when none in fact exists.

The Chow and predictive failure tests will work satisfactorily if the date of a structural break in a financial time series can be specified. But more often, a researcher will not know the break date in advance, or may know only that it lies within a given range (sub-set) of the sample period. In such circumstances, a modified version of the Chow test, known as the *Quandt likelihood ratio (QLR) test*, named after Quandt (1960), can be used instead. The test works by automatically computing the usual Chow *F* test statistic repeatedly with different break dates, then the break date giving the largest *F*-statistic value is chosen. While the test statistic is of the *F*-variety, it will follow a non-standard distribution rather than an *F*-distribution since we are selecting the largest from a number of *F*-statistics rather than examining a single one. The test is well behaved only when the range of possible break dates is sufficiently far from the end points of the whole sample, so it is usual to ‘‘trim’’ the sample by (typically) 5% at each end. The critical values will depend on how much of the sample is trimmed away, the number of restrictions under the null hypothesis (the number of regressors in the original regression as this is effectively a Chow test) and the significance level.

OLS Analysis

We apply OLS (with lag order equal to 2) in order to estimate the regression coefficients of the equation (1), for the time period 1994:1 – 2012:2. The results are shown in table 6.

Table 6.OLS test

OLS, using observations 1994:1-2012:2 (T = 74)					
Dependent variable: d_l_SCHFUSD					
HAC standard errors, bandwidth 3 (Bartlett kernel)					
	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	-0.0247819	0.00786958	-3.1491	0.00241	***
LM3_dif	-0.0326227	0.0104667	-3.1168	0.00265	***
LM3_dif_1	0.0428017	0.017611	2.4304	0.01765	**
LM3_dif_2	-0.0197054	0.0117761	-1.6733	0.09872	*

Mean dependent var	-0.006071	S.D. dependent var	0.043313
Sum squared resid	0.117363	S.E. of regression	0.040946
R-squared	0.143008	Adjusted R-squared	0.106280
F(3, 70)	6.120595	P-value(F)	0.000930
Log-likelihood	133.5209	Akaike criterion	-259.0417
Schwarz criterion	-249.8255	Hannan-Quinn	-255.3652
rho	0.115625	Durbin-Watson	1.756388

Note: The full table is depicted in the Annex.

Following the OLS analysis and as previously explained, we perform the QLR test to examine the possibility of structural break at an unknown point. As per the Quandt test which is depicted in table 7, we result to maximum F at observation 2008:2, significant at 5% level. It is strong evidence that the structural break occurred at 2008:2, very close to our initial thoughts and to the recent global financial crisis. Figure 5 shows the plot of QLR test.

Table 7. QUANDT test

`Quandt likelihood ratio test for structural break at an unknown point,`
`with 15 percent trimming:`
`The maximum F(4, 66) = 4.37399 occurs at observation 2008:2`
`Significant at the 5 percent level (5% critical value = 4.09)`

Note: The full table is depicted in the Annex.

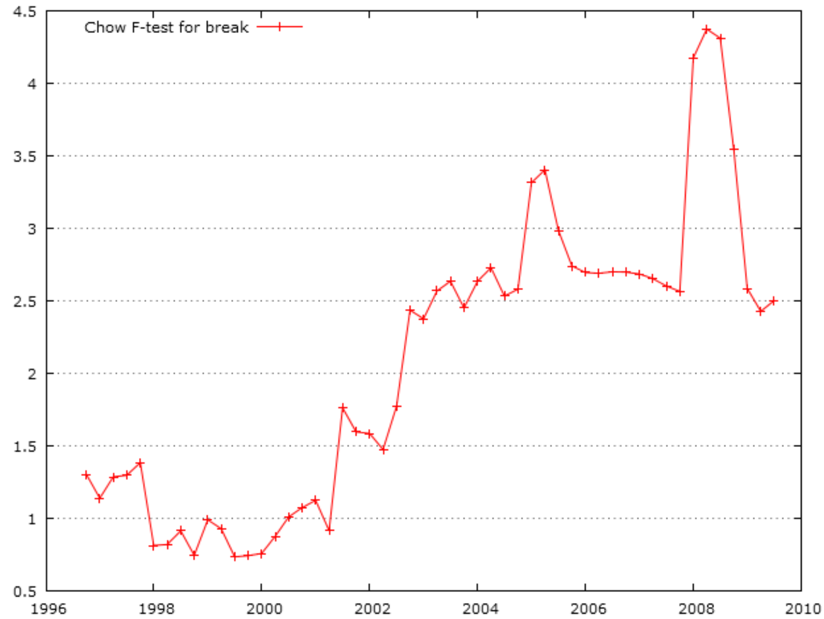

Figure 5. Quandt test

Continuing the OLS analysis, we apply the Chow test for structural break at observation 2008:2. The results of Chow test are depicted at table 8.

Table 8. Chow test

	coefficient	p-value	
const	-0.0372391	3.93e-07	***
LM3_dif	-0.0269789	0.0121	**
Dummy	4.34581e-05	0.9985	
Du_LM3_dif	-0.191768	0.0024	***
Du_LM3_dif_1	0.137095	0.0011	***

Mean dependent var	-0.006071	S.D. dependent var	0.043313
Sum squared resid	0.092770	S.E. of regression	0.037491
R-squared	0.322584	Adjusted R-squared	0.250737
F(7, 66)	9.459528	P-value(F)	4.51e-08
Log-likelihood	142.2212	Akaike criterion	-268.4424
Schwarz criterion	-250.0098	Hannan-Quinn	-261.0894
rho	0.006081	Durbin-Watson	1.966726

Chow test for structural difference with respect to Dummy
Chi-square(4) = 29.4702 with p-value 0.0000
F-form: F(4, 66) = 7.36756 with p-value 0.0001

Note: The full table is depicted in the Annex.

Considering the structural break at observation 2008:2, equation (1) is transformed in two new equations. The first one explains the time period before the structural break and the second one explains the time period after the structural break.

According to the results of the regression as shown in table 8, the differential slope coefficients at t and t-1 are statistically significant. So, the mentioned equations are shown below:

- **Time period: 1994:1 – 2001:2**

$d\_l\_SCHFUSD_t = -0{,}037 - 0{,}027\ LM3\_dif_t$

- **Time period: 2008:2 – 2012:2**

$d\_l\_SCHFUSD_t = -0{,}037 - (0{,}027+0{,}19)LM3\_dif_t + 0{,}137LM3\_dif_{t-1}$

$d\_l\_SCHFUSD_t = -0{,}037 - 0{,}217\ LM3\_dif_t + 0{,}137\ LM3\_dif_{t-1}$

The evidence reported in tables 6 and 8 reveals that the results are qualitative similar to those obtained before (period 1994:1 – 2008:4), indicating that the UIP is supported by the empirical analysis, without accepting the theoretical restrictions.

5. Conclusions

UIP theory states that the gains due to interest-rate differentials (IRDs) are offset by the loss arising in the depreciation of the target currency. Stated in its simplest terms, UIP implies that, if financial markets are efficient, it should not be possible to make profit by borrowing funds with low interest rate in a domestic currency, switching the funds borrowed into another (foreign) currency, investing them there with higher interest rate and finally switching the funds back to the domestic country earning the interest rate difference. The difference between the expected spot rate at time (t+1) and the spot rate at time t should offset any gain.

Using quarterly data from the period 1994:1 – 2012:2, we examine the uncovered interest parity for the Swiss franc – US dollar exchange rate accounting for interest rate dynamics. Firstly we find a relationship for the period 1994:1 – 2008:4 and afterwards we increase our sample by running the same regression until 2012. The results for both periods are qualitatively similar indicating that the UIP is supported by the empirical analysis, without accepting the theoretical restrictions. More detailed, could be mentioned that:

(1) The interest rate differentials are little use as predictors of movements in exchange rates since they explain only a relatively small proportion of the observed variance in exchange rates.

(2) The signs of all parameters in the relationship CHF/USD movements, against IRDs, are in the correct sign, meaning that a rise in the domestic interest rate induces an instantaneous appreciation of the CHF against the USD because of capital inflows that want to take advantage of higher interest rates. This is shown by the contemporaneous relationship which is negative. However later in time, the investors will switch the funds back in USA causing depreciation of the Swiss Franc. This is shown by the relationship between the change in the exchange rate and the sum of the lagged values of IRD which is positive and statistically significant, indicating that an increase in IRD will depreciate the exchange rate (CHF), something which accords with the theory.

(3) A structural break at time 2008:2 is identified. The financial crisis of 2008, forced Switzerland and especially USA to drop the interest rates and maintain them close to zero. This break affected the regression model as was expected by changing the values of the slope coefficients. However the signs of both the contemporaneous relationship and the sum of the lagged values of IRD were maintained the same with the period 1994:1 – 2008:4.

Annex - Tables

Table 1

D_l_SCHFUSD

```
Dickey-Fuller test for d_l_SCHFUSD
sample size 60
unit-root null hypothesis: a = 1

   test with constant
   model: (1-L)y = b0 + (a-1)*y(-1) + e
   1st-order autocorrelation coeff. for e: 0.005
   estimated value of (a - 1): -0.754246
   test statistic: tau_c(1) = -5.73092
   p-value 8.123e-006

Dickey-Fuller regression
OLS, using observations 1994:1-2008:4 (T = 60)
Dependent variable: d_d_l_SCHFUSD

                  coefficient   std. error   t-ratio   p-value
  -------------------------------------------------------------
  const           -0.00267093   0.00529479   -0.5044   0.6159
  d_l_SCHFUSD_1   -0.754246     0.131610     -5.731    8.12e-06 ***

  AIC: -212.082   BIC: -207.893   HQC: -210.444

   with constant and trend
   model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + e
   1st-order autocorrelation coeff. for e: 0.005
   estimated value of (a - 1): -0.757848
   test statistic: tau_ct(1) = -5.67327
   p-value 7.886e-005

Dickey-Fuller regression
OLS, using observations 1994:1-2008:4 (T = 60)
Dependent variable: d_d_l_SCHFUSD

                  coefficient    std. error    t-ratio   p-value
  ---------------------------------------------------------------
  const            0.00239288    0.0222537      0.1075   0.9147
  d_l_SCHFUSD_1   -0.757848      0.133582      -5.673    7.89e-05 ***
  time            -7.20987e-05   0.000307597   -0.2344   0.8155

  AIC: -210.14   BIC: -203.857   HQC: -207.682
```

LM3_dif

```
Augmented Dickey-Fuller test for LM3_dif
including one lag of (1-L)LM3_dif (max was 4)
sample size 60
unit-root null hypothesis: a = 1

   test with constant
   model: (1-L)y = b0 + (a-1)*y(-1) + ... + e
   1st-order autocorrelation coeff. for e: -0.063
   estimated value of (a - 1): -0.0918097
   test statistic: tau_c(1) = -2.88492
   asymptotic p-value 0.04711

Augmented Dickey-Fuller regression
OLS, using observations 1994:1-2008:4 (T = 60)
Dependent variable: d_LM3_dif

                coefficient   std. error   t-ratio   p-value
  -----------------------------------------------------------
  const         -0.229432     0.0884747    -2.593    0.0121   **
  LM3_dif_1     -0.0918097    0.0318239    -2.885    0.0471   **
  d_LM3_dif_1    0.599739     0.101542      5.906    2.05e-07 ***

  AIC: 54.0279   BIC: 60.311   HQC: 56.4856

   with constant and trend
   model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + ... + e
   1st-order autocorrelation coeff. for e: -0.042
   estimated value of (a - 1): -0.0984681
   test statistic: tau_ct(1) = -3.0864
   asymptotic p-value 0.1095

Augmented Dickey-Fuller regression
OLS, using observations 1994:1-2008:4 (T = 60)
Dependent variable: d_LM3_dif

                coefficient   std. error   t-ratio   p-value
  -----------------------------------------------------------
  const         -0.542239     0.238651     -2.272    0.0269   **
  LM3_dif_1     -0.0984681    0.0319038    -3.086    0.1095
  d_LM3_dif_1    0.544086     0.108142      5.031    5.36e-06 ***
  time           0.00419468   0.00297624    1.409    0.1642

  AIC: 53.9365   BIC: 62.3139   HQC: 57.2134
```

Table 2

```
VAR system, maximum lag order 4

The asterisks below indicate the best (that is, minimized) values
of the respective information criteria, AIC = Akaike criterion,
BIC = Schwarz Bayesian criterion and HQC = Hannan-Quinn criterion.

lags        loglik     p(LR)       AIC           BIC           HQC

   1       91.58377              -2.313075     -2.126259     -2.238552
   2      109.58673   0.00000    -2.691533*    -2.380173*    -2.567328*
   3      111.98823   0.30812    -2.648331     -2.212426     -2.474443
   4      117.15710   0.03511    -2.679921     -2.119473     -2.456352
```

Table 3

Model 43: OLS, using observations 1994:1-2008:4 (T = 60)
Dependent variable: d_l_SCHFUSD
HAC standard errors, bandwidth 2 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	-0.030907	0.00806897	-3.8304	0.00033	***
LM3_dif	-0.0324753	0.0103932	-3.1247	0.00282	***
LM3_dif_1	0.0438805	0.0190673	2.3013	0.02512	**
LM3_dif_2	-0.0227444	0.0120747	-1.8836	0.06481	*

Mean dependent var	-0.003978	S.D. dependent var	0.041501
Sum squared resid	0.083846	S.E. of regression	0.038694
R-squared	0.174903	Adjusted R-squared	0.130702
F(3, 56)	7.379018	P-value(F)	0.000299
Log-likelihood	112.0573	Akaike criterion	-216.1146
Schwarz criterion	-207.7372	Hannan-Quinn	-212.8377
rho	0.047076	Durbin-Watson	1.816603

Table 4

Variables: LM3_dif_1 LM3_dif_2
Sum of coefficients = 0.0211361
Standard error = 0.0105726
t(56) = 1.99914 with p-value = 0.0504547

Table 5

D_l_SCHFUSD

```
Dickey-Fuller test for d_l_SCHFUSD
sample size 74
unit-root null hypothesis: a = 1

   test with constant
   model: (1-L)y = b0 + (a-1)*y(-1) + e
   1st-order autocorrelation coeff. for e: 0.021
   estimated value of (a - 1): -0.777225
   test statistic: tau_c(1) = -6.75079
   p-value 3.181e-007

Dickey-Fuller regression
OLS, using observations 1994:1-2012:2 (T = 74)
Dependent variable: d_d_l_SCHFUSD

                  coefficient   std. error   t-ratio   p-value
  -------------------------------------------------------------
  const           -0.00464796   0.00499735   -0.9301   0.3554
  d_l_SCHFUSD_1   -0.777225     0.115131     -6.751    3.18e-07 ***

  AIC: -255.373   BIC: -250.765   HQC: -253.535

   with constant and trend
   model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + e
   1st-order autocorrelation coeff. for e: 0.022
   estimated value of (a - 1): -0.785099
   test statistic: tau_ct(1) = -6.75003
   p-value 1.38e-006

Dickey-Fuller regression
OLS, using observations 1994:1-2012:2 (T = 74)
Dependent variable: d_d_l_SCHFUSD

                  coefficient    std. error    t-ratio   p-value
  ---------------------------------------------------------------
  const            0.00659813    0.0187227      0.3524   0.7256
  d_l_SCHFUSD_1   -0.785099      0.116310      -6.750    1.38e-06 ***
  time            -0.000145760   0.000233782   -0.6235   0.5350

  AIC: -253.777   BIC: -246.865   HQC: -251.02
```

LM3_dif

```
Augmented Dickey-Fuller test for LM3_dif
including one lag of (1-L)LM3_dif (max was 4)
sample size 74
unit-root null hypothesis: a = 1

   test with constant
   model: (1-L)y = b0 + (a-1)*y(-1) + ... + e
   1st-order autocorrelation coeff. for e: -0.026
   estimated value of (a - 1): -0.062933
   test statistic: tau_c(1) = -2.43561
   asymptotic p-value 0.1319

Augmented Dickey-Fuller regression
OLS, using observations 1994:1-2012:2 (T = 74)
Dependent variable: d_LM3_dif

                coefficient   std. error   t-ratio   p-value
  -----------------------------------------------------------
  const         -0.127157     0.0648087    -1.962    0.0537   *
  LM3_dif_1     -0.0629330    0.0258387    -2.436    0.1319
  d_LM3_dif_1    0.575511     0.0934455     6.159    3.93e-08 ***

  AIC: 57.8662   BIC: 64.7784   HQC: 60.6236

   with constant and trend
   model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + ... + e
   1st-order autocorrelation coeff. for e: -0.017
   estimated value of (a - 1): -0.0945994
   test statistic: tau_ct(1) = -3.39599
   asymptotic p-value 0.05184

Augmented Dickey-Fuller regression
OLS, using observations 1994:1-2012:2 (T = 74)
Dependent variable: d_LM3_dif

                coefficient   std. error   t-ratio   p-value
  -----------------------------------------------------------
  const         -0.610034     0.200329     -3.045    0.0033   ***
  LM3_dif_1     -0.0945994    0.0278562    -3.396    0.0518   *
  d_LM3_dif_1    0.511023     0.0935803     5.461    6.80e-07 ***
  time           0.00541170   0.00213320    2.537    0.0134   **

  AIC: 53.3575   BIC: 62.5738   HQC: 57.034
```

Table 6

Model 5: OLS, using observations 1994:1-2012:2 (T = 74)
Dependent variable: d_l_SCHFUSD
HAC standard errors, bandwidth 3 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	-0.0247819	0.00786958	-3.1491	0.00241	***
LM3_dif	-0.0326227	0.0104667	-3.1168	0.00265	***
LM3_dif_1	0.0428017	0.017611	2.4304	0.01765	**
LM3_dif_2	-0.0197054	0.0117761	-1.6733	0.09872	*

Mean dependent var	-0.006071	S.D. dependent var	0.043313
Sum squared resid	0.117363	S.E. of regression	0.040946
R-squared	0.143008	Adjusted R-squared	0.106280
F(3, 70)	6.120595	P-value(F)	0.000930
Log-likelihood	133.5209	Akaike criterion	-259.0417
Schwarz criterion	-249.8255	Hannan-Quinn	-255.3652
rho	0.115625	Durbin-Watson	1.756388

Table 7

QUANDT test

```
Quandt likelihood ratio test for structural break at an unknown point,
with 15 percent trimming:

The maximum F(4, 66) = 4.37399 occurs at observation 2008:2
Significant at the 5 percent level (5% critical value = 4.09)

This statistic does not follow the standard F distribution;
critical values are from Stock and Watson (2003).
```

Table 8

Chow test

```
Augmented regression for Chow test
OLS, using observations 1994:1-2012:2 (T = 74)
Dependent variable: d_l_SCHFUSD
HAC standard errors, bandwidth 3 (Bartlett kernel)

                 coefficient    std. error    t-ratio    p-value
  --------------------------------------------------------------
  const          -0.0372391     0.00660983   -5.634      3.93e-07 ***
  LM3_dif        -0.0269789     0.0104507    -2.582      0.0121   **
  LM3_dif_1       0.0352640     0.0234634     1.503      0.1376
  LM3_dif_2      -0.0214482     0.0162286    -1.322      0.1909
  Dummy           4.34581e-05   0.0225187     0.001930   0.9985
  Du_LM3_dif     -0.191768      0.0607993    -3.154      0.0024   ***
  Du_LM3_dif_1    0.137095      0.0401354     3.416      0.0011   ***
  Du_LM3_dif_2   -0.0298019     0.0244443    -1.219      0.2271

Mean dependent var  -0.006071   S.D. dependent var   0.043313
Sum squared resid    0.092770   S.E. of regression   0.037491
R-squared            0.322584   Adjusted R-squared   0.250737
F(7, 66)             9.459528   P-value(F)           4.51e-08
Log-likelihood       142.2212   Akaike criterion    -268.4424
Schwarz criterion   -250.0098   Hannan-Quinn        -261.0894
rho                  0.006081   Durbin-Watson        1.966726

Chow test for structural difference with respect to Dummy
  Chi-square(4) = 29.4702 with p-value 0.0000
  F-form: F(4, 66) = 7.36756 with p-value 0.0001
```

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