THE CARRY TRADE AND THE ADJUSTMENT OF THE JAPANESE YEN: EVIDENCE FROM A MARKOV-SWITCHING VECTOR AUTOREGRESSION MODEL

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Abstract

Carry trades are speculative activities which involve simultaneously going short a low-rate currency and long a high-rate currency. They are profitable as long as the gains from interest rate differentials are not offset by exchange rate movements. In this paper I investigate the dynamic relationships amongst exchange rate changes, interest rate spreads and carry trades by means of a Markov-switching vector autoregression model. I use regime-dependent impulse response functions to assess (1) how and to what extent shocks to the interest rate differential and the bilateral exchange rate affect the yen carry trade; (2) the consequences of the unwinding of the yen carry trade on the dollar-yen exchange rate. Empirical evidence indicates the presence of a so-called "carry trade" regime, whose timing is consistent with the yen carry trade episodes identified in the literature. Moreover, only when the system is in the "carry trade" regime a shock in the carry-to-risk ratio has a positive and significant effect on the net short positions in Japanese yen and the depreciation of the yen against the dollar is strong and persistent. Finally, a rising carry-to-risk ratio, which in turn reveals an increase in the attractiveness of carry trades, leads to a significant depreciation of the yen only when the system is in the "carry-trade" regime.

Keywords: Uncovered interest parity; Forward premium puzzle; Carry trade; Markov-switching vector autoregression model

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1. Introduction

A currency carry trade is an investment strategy which involves selling money in low interest-rate currencies – "funding currencies" – and investing in high interest-rate currencies – "target currencies". If the target currency does not depreciate vis-à-vis the funding currency during investment horizon, then the investor earns at least the interest differential.

According to economic theory, an investment strategy based on exploiting differences in interest rates across countries should yield no predictable profits as "uncovered interest parity" (UIP) should hold. In particular, according to the UIP condition the carry gains due to the interest-rate differential are offset by a commensurate depreciation of the investment currency. However, empirically has been shown that the reverse holds and in many cases currencies with high interest rates tend to appreciate while those with low interest rates depreciate[1]. This violation of the UIP, named "forward premium puzzle" by Fama (1984), is what makes the carry trade profitable on average. Moreover, carry trades tend to be pursued only when the interest differential between target and the funding currencies is wide enough to compensate for the foreign exchange risk being taken in the short to medium term. A popular ex ante gauge of the attractiveness of carry trades is the carry-to-risk ratio (Galati et al. (2007)). It adjusts the interest rate differential by the risk of future exchange rate movements, where this risk is measured by the expected volatility (implied by foreign exchange options) of the relevant currency pair. Accordingly, a relatively low volatility environment may increase the expected profitability of carry trades, encouraging further speculative positioning.

The carry trade has been increasingly attracting the attention of the financial press over the last ten years as both market participants and monetary authorities[2] have agreed that the weakness of lower-interest currencies and the unexpected enthusiasm of investors for high-yielding currencies have been influenced by carry trade activities. In particular, in the case of Japan, the availability of cheap funds along with the relatively low volatility in the currency has made the Japanese yen an ideal funding currency. The Bank of International Settlements (BIS) has been constantly monitoring the carry trade activity throughout the years, providing a great deal of evidence consistent with the presence of such activity and showing that its effect on exchange rates can be significant, both in terms of trend and in terms of volatility.

This study investigates the relationship between the Japanese yen US dollar bilateral exchange rate, the interest rate differential and exchange rate volatility in order to understand the conditions under which carry trades tend to accumulate and then unwind. The focus is on the carry trade in Japanese yen for a number of reasons. First, the yen is the currency most commonly cited by market participants as the funding currency for carry trades; second, Japan has had the lowest interest rates in the world

[1] See, for example, Burnside et al. (2006).

[2] For instance, de Rato (2007) mentioned that the carry trade reflects low volatilities and large interest rate differentials, which has exerted downward pressure on one of the lowest-interest currencies, the Japanese yen. He also warned that the unwinding of the carry trade positions could lead to rapid reversal movements of exchange rates.

for more than 10 years; finally, it has been shown that the failure of UIP in low volatility environment is mostly evident for the Japanese yen (Ichiue and Koyama (2008)).

The discussion above has made clear that the carry trade strategy is profitable only when particular market conditions are fulfilled. In particular, carry trades tend to be pursued only as long as the gains from interest rate differentials are not expected to be overwhelmed by exchange rate movements. For this reason, a framework with constant parameters (see, e.g., Nishigaki (2007)) does not seem to be appropriate. To shed some light on the dynamic relationships amongst interest rate differentials, exchange rate changes and carry trades I take a Markov-switching vector autoregression (MS VAR) approach. This setting has the attractive feature of allowing the system to distinguish between phases in which the carry trade strategy might be profitable and phases in which the carry trade strategy might not be profitable. Central to the MS VAR approach is the use of regime-dependent impulse response analysis, which traces out how fundamental disturbances affect the variables in the model dependent on the regime. Instead of one set of impulse response functions we have a set for each regime. In this study I use regime-dependent impulse response functions to assess (1) how and to what extent shocks to the interest rate differential and the bilateral exchange rate affect the yen carry trade; (2) the consequences of the unwinding of the yen carry trade on the dollar-yen exchange rate. Empirical evidence indicates the presence of a so-called "carry trade" regime, whose timing is consistent with the yen carry trade episodes identified in the literature and whose features are compatible with the presence of carry trade activities. The regime-dependent impulse response analysis shows that only when the system is in the "carry trade" regime a shock in the carry-to-risk ratio has a positive and significant effect on the net short positions in Japanese yen, while shocks to the bilateral exchange rate returns affect the yen carry trade only in the short-run in both regimes. Moreover, an increase in the yen carry trade generally leads to a persistent depreciation of the yen against the dollar but in the "carry-trade" regime such depreciation is stronger and persistent. Finally, a rising carry-to-risk ratio, which in turn reveals an increase in the attractiveness of carry trades, leads to a significant depreciation of the yen only when the system is in the "carry-trade" regime.

In order to shed further light on the impact that the interest rate spread and exchange rate volatility might have on the regime classification identified by the MS VAR, I also set up a simple probit model. The estimation results confirm that the probability of being in the "carry trade" regime is positively affected by increasing interest rate spreads and negatively affected by foreign exchange rate risk (measured by the realized volatility of the exchange rate).

The reminder paper is structured as follows. Section 2 provides a brief review of the related literature. In Section 3, a Markov-switching vector autoregression model is presented together with a separate set of regime-dependent impulse response functions for each regime. Section 4 describes the data sources and defines the variable used in the model I specify. The main estimation results are presented in Section 5 and Section 6 concludes.

2. UIP Failure and Carry Trades: a Brief Literature Review

There is a comprehensive literature in macroeconomics and finance on the failure of UIP and the forward premium puzzle, which deals implicitly with the mean return of the carry trade.[3] From an economic perspective the low empirical support for the UIP theorem might be justified adducing the presence of a risk premium or market inefficiency. Nonetheless, attempts to explain the forward bias using models of risk premia (e.g. Cumby (1988), Hodrick (1989), and Bekaert et al. (1997)) have had only limited success and studies focussing on alternative explanations such as learning, peso problems and bubbles (e.g. Lewis (1995)), consumption-based asset pricing theories (e.g. Backus et al. (1993), Bekaert (1996)), and term-structure models (e.g. Backus et al. (2001), have not been able to provide convincing explanations for the forward premium puzzle. More recently, Bacchetta and van Wincoop (2007) ascribe the failure of UIP to infrequent revisions of investor portfolio decisions.

While market evidence suggests that carry trades are the most widely used currency speculation strategy (e.g. Galati and Melvin (2004)), recent academic research largely supports the existence of limits to speculation. Sarno et al. (2006) and Baillie and Kiliç (2006) investigate the relationship between spot and forward rates in a smooth transition regression framework. Both articles provide empirical evidence that deviations from the UIP display significant nonlinearities but show that (expected) deviations from UIP are too small to attract speculative capital. Furthermore, Burnside et al. (2006) argue that the existence of transaction costs and price pressure drastically reduce the returns to currency speculation.[4] The recent study of Wagner (2008) adds to this branch of literature and tests the speculative efficiency of currency markets by assessing the economic significance of currency speculation profits. The author finds support for speculative UIP and the existence of a risk-premium but shows that currency speculation does not yield economically significant excess returns, which suggests that foreign exchange markets are speculatively efficient.

The analysis of Brunnermeier et al. (2008) examines empirically the skewness of exchange rate movements conditional on the interest rate differential, i.e. on the crash risk of carry trade strategies. The authors provide evidence consistent with a theory that currency crashes are often the result of endogenous unwinding of carry trade activity which tend to occur in periods in which risk appetite and funding liquidity decrease. Bhansali (2007) provides evidence supporting a positive relationship between currency volatility and the carry trade and documents that option based carry trades yield excess returns. The link between exchange rate volatility and build-up of carry trade positions is also acknowledged in a recent study of Ichiue and Koyama (2008). They estimate a regime-switching model of currency returns to examine how volatility affect the failure of UIP and find that in a low-volatility environment, the carry trade and its rapid unwinding do influence exchange rates

[3] Surveys of the literature include Froot and Thaler (1990), Taylor (1995), Engel (1996) and Sarno and Taylor (2003).

[4] The Sharpe ratio is the risk-adjusted return of an asset; typically, it is the return of an asset relative to a benchmark asset, weighted by the standard deviation of excess return.

substantially. In particular, they introduce an interest rate differential as state-dependent regressor in a univariate four-regime model, in which the state variables are not necessarily perfectly dependent nor independent. Four main findings are presented in their study: first, regime switches in exchange rate returns should be interpreted as switches in the relationship between the returns and interest rate differentials, which, in turn, might be read as switches between the carry trade and its unwinding; second, currencies featuring low interest rates appreciate less frequently compared to the high-interest-rate ones, but once it occurs, the appreciation is faster than the depreciation. This may be due to the fact that the former is influenced by an unwinding of the carry trade. Third, a low exchange rate volatility tends to cause the UIP to fail and vice versa. In particular, the authors find that the failure of the UIP contributes to maintaining a lower-volatility environment, which might entail that a high volatility does not tend to occur until an unwinding of the carry trade. Finally, the second and third findings turns out to be more evident for shorter maturities, validating the idea that UIP failure is indeed affected by short-term speculations. Gagnon and Chaboud (2007) use a broad range of data sources to explore the carry trade in Japanese yen and devoted special attention to the most recent episodes in which yen carry trades are commonly reported to have unwound rapidly (October 1998, May 2006 and February 2007), linking the crashes to balance sheet data of the offcial sector, the Japanese banking sector and households. Galati et al. (2007) and McGuire and Upper (2007) employ several datasets, including the BIS international banking statistics and data on turnover in foreign exchange markets, looking for evidence on the importance of global carry trades. They cautiously conclude that the analysed data did shed light on specific market segments where carry trade activity was likely to be evident. Klitgaard and Weir (2004) use weekly net position data on futures traded on the Chicago Mercantile Exchange – the same used in this paper - and document a contemporaneous relationship between weekly changes in speculators' net positions and exchange rate movements. The paper of Nishigaki (2007) focuses on the US and Japanese financial markets and addresses two issues. First, it identifies the financial factors that have a significant role in explaining the yen carry trade: the change in interest rate differential and the change in investors´ risk aversion; second, it explores the consequences of carry trade unwinding by constructing a six-dimensional structural vector autoregression model with monthly data from January 1993 to January 2007. The author's main conclusion is threefold. First, the interest rate differential between the US and Japan does not significantly affect the movement of the yen carry trade. According to Nishigaki (2007), this apparently counterintuitive result might reflect the fact that the spread between Japanese and US interest rates is so wide that an interest rate differential shock would ultimately leave the attractiveness of the carry trade unaffected. Second, the financial variable that can have a dominant impact on the yen carry trade is the US stock price and finally, the carry trade has a significant impact on the exchange rate. Evidence of substantial speculative outflows, through carry trades, which complicates the outlook for the Japanese currency, is also found in Winters (2008). The author develops a portfolio model to address the underlying motivation for capital outflows from Japan over the past ten years and

devotes special attention to the carry trade in order to understand its role on the yen's ongoing weakness. The evidence presented in the paper suggests that part of the capital outflows has indeed speculative nature and is related to Japan´s low yields and a potential decline in risk aversion by investors.

This study takes the analysis of Nishigaki (2008) a step forward and, in line with the work of Ichiue and Koyama (2008)[5], investigates the relationship among exchange rate returns, exchange rate volatility, and interest rate differentials in a non-linear context. In particular, in order to allow the system to distinguish between phases in which the carry trade strategy might be profitable and phases in which the carry trade strategy might not be profitable, I estimate a MS VAR model and calculate regime-dependent impulse response functions to trace out how fundamental disturbances affect the variables in the model dependent on the regime.

3. The Econometric Model

3.1 A Markov-switching Vector Autoregression Model

Define $\mathbf{Y}_t$ as a vector of K endogenous variables explained by an intercept, c_i, p autoregressive terms and a residual $\boldsymbol{A}_i e_t$. Moreover, $S_t = \{1 \ldots M\}$ is a M-state unobserved variable, following a first order Markov Chain. Finally, the probability of being in regime j next period conditional on the current regime i is assumed to be exogenous and constant.

$$\Pr\left(s_{t+1} = j s_{t+1} = j \middle| s_t = i\right) = \rho_{ij} \tag{1}$$

In an M-state model such conditional probabilities are collected into an (M x M) transition matrix, **P**.

$$\mathbf{P} = \begin{bmatrix} \rho_{11} & \rho_{12} & \cdots & \rho_{1M} \\ \rho_{21} & \rho_{22} & \cdots & \rho_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{M1} & \rho_{M2} & \cdots & \rho_{MM} \end{bmatrix} \tag{2}$$

Equation (3) represents the most general specification of a Markov-switching vector autoregressive model (MS VAR) ,where all parameters of the autoregression are allowed to switch between regimes

[5] Ichiue and Koyama (2008) focus on how exchange rate volatility influences the failure of UIP by using a univariate regime-switching model of currency returns. The analysis carried out in this paper investigates the dynamic relationships amongst exchange rate changes, interest rate spreads and carry trades by means of a Markov-switching vector autoregression model.

so each of the M regimes is characterised by an intercept , c_i, autoregressive terms $\boldsymbol{B}_{1i}$, …$\boldsymbol{B}_{pi}$ and a matrix $\boldsymbol{A}_i$.

$$Y_t = \begin{cases} c_1 + B_{11}Y_{t-1} + \ldots + B_{p1}X_{t-p} + A_1 e_t & \text{if } s_t = 1 \\ \vdots & \\ c_M + B_{1M}Y_{t-1} + \ldots + B_{pM}X_{t-p} + A_M e_t & \text{if } s_t = M \end{cases} \tag{3}$$

$$\mathbf{e}_t \sim N(\mathbf{0}, \mathbf{I_K})$$

$\mathbf{e}_t$ is a K-dimensional vector of fundamental disturbances which are assumed to be normally distributed and uncorrelated. The variance of each fundamental disturbance is normalized to unity to give the identity variance-covariance matrix. However, $\boldsymbol{\Sigma}_i$, the variance-covariance matrix of the residuals $\boldsymbol{A}_i e_t$, will still be regime dependent as the fundamental disturbances are premultiplied by the regime-dependent matrix $\boldsymbol{A}_i$.

Estimation of a Markov-switching model entails joint estimation of all the parameters and the hidden Markov chain followed by the regimes. Given the recursive nature of the likelihood function, i.e. optimal inference in the current period depends on the optimal inference in the previous period, the model is recursively estimated by means of the Expectations-Maximization (EM) algorithm (Hamilton (1990) and Krolzig (1997)). Starting from the unconditional density of $\mathbf{Y_t}$ which is calculated by summing conditional densities over possible values for S_t

$$f(Y_t \mid I_{t-1}, \boldsymbol{\Theta}) = \sum_{j=1}^{M} P(S_t = j, Y_t \mid I_{t-1,} \boldsymbol{\Theta}) \tag{4}$$

where I_{t-1} = (Y_{t-1}, . . . , Y_1) denoting the information set available in t-1, the maximum likelihood estimate of the parameters, Θ, is obtained by maximizing the log-likelihood:

$$L(\boldsymbol{\Theta}) = \sum_{t=1}^{T} \ln(\, f(Y_t \mid I_{t-1}, \boldsymbol{\Theta})) \tag{5}$$

Besides estimates of the parameters associated with each regime, $\left\{\hat{v}_i; \hat{B}_{1i}, \ldots, \hat{B}_{pi}; \hat{\Sigma}_i\right\}$ for i = 1, …, M and the transition probability matrix, $\hat{P}$, the EM algorithm allows to construct the so-called smoothed probabilities, $\hat{\xi}_{i,t} = \Pr(S_t = i)$, for i = 1, …, M and t =1, …, T, an optimal inference of the hidden Markov chain followed by the regime.

The focus of my analysis is the relationship between the fundamental disturbances and the endogenous variables for each regime. As the EM algorithm gives only estimates of the variance-covariance

matrices $\mathbf{\Sigma}_1$, …, $\mathbf{\Sigma}_m$, it is necessary to impose restrictions on the parameter estimates from the unrestricted model in order to identify the matrices $\mathbf{A}_1$, …, $\mathbf{A}_m$. Here I chose the recursive identification scheme derived by Sims (1980), where the endogenous variables are ordered and it is assumed that the structural disturbance to a variable has only contemporaneous effects on the variable itself and on variables ordered below it. For example, in a three variables system the second disturbance has only contemporaneous effects on the second and the third endogenous variables. Under this identification procedure the matrix $\mathbf{A}_i$ is lower triangular and exactly identified. In this study $\hat{\mathbf{A}}_i$ is identified by a Choleski decomposition of the estimated matrix $\hat{\mathbf{\Sigma}}_i$.

3.2 Regime-dependent Impulse Response Functions

Standard impulse response analysis describes how the endogenous variables in the model react to the fundamental disturbances. One way to extend this concept to a Markov-switching framework is to define the regime-dependent impulse response function (IRFs). This describes the relationship between endogenous variables and fundamental disturbances within regimes. Regime-dependent IRFs are conditional on the regime prevailing at the time of the disturbance and throughout the duration of the response. The plausibility of regime conditioning depends on two factors: the time horizon of the impulse response and the expected duration of the regime. As long as the time horizon is not excessively long and the transition matrix indicates regimes which are persistent then the conditioning is valid and regime-dependent IRFs are a useful analytical tool. When the considered time horizon are relatively long and characterized by frequent regime switches, it would be more correct to calculate the Generalized IRFs of Koop, Pesaran and Potter (1996), which condition on the expected path of the regime throughout the response. However, the additional information contained into the Generalized IRFs is limited when regime switches are exogenous and regimes are persistent.

In the general model described above, there are MK^2 regime-dependent IRFs, each one being the reaction of the K variables to the K disturbances in M regimes. Equation (6) defines the regime-dependent IRFs for regime i, a series of K-dimensional response vectors , $\boldsymbol{\theta}_{ki,1}$…, $\boldsymbol{\theta}_{ki,h}$.

$$\left.\frac{\partial E_t Y_{t+h}}{\partial e_{k,t}}\right|_{s_t=\ldots=s_{t+h}=i} = \theta_{ki,h} \quad \text{for } h \geq 0 \tag{6}$$

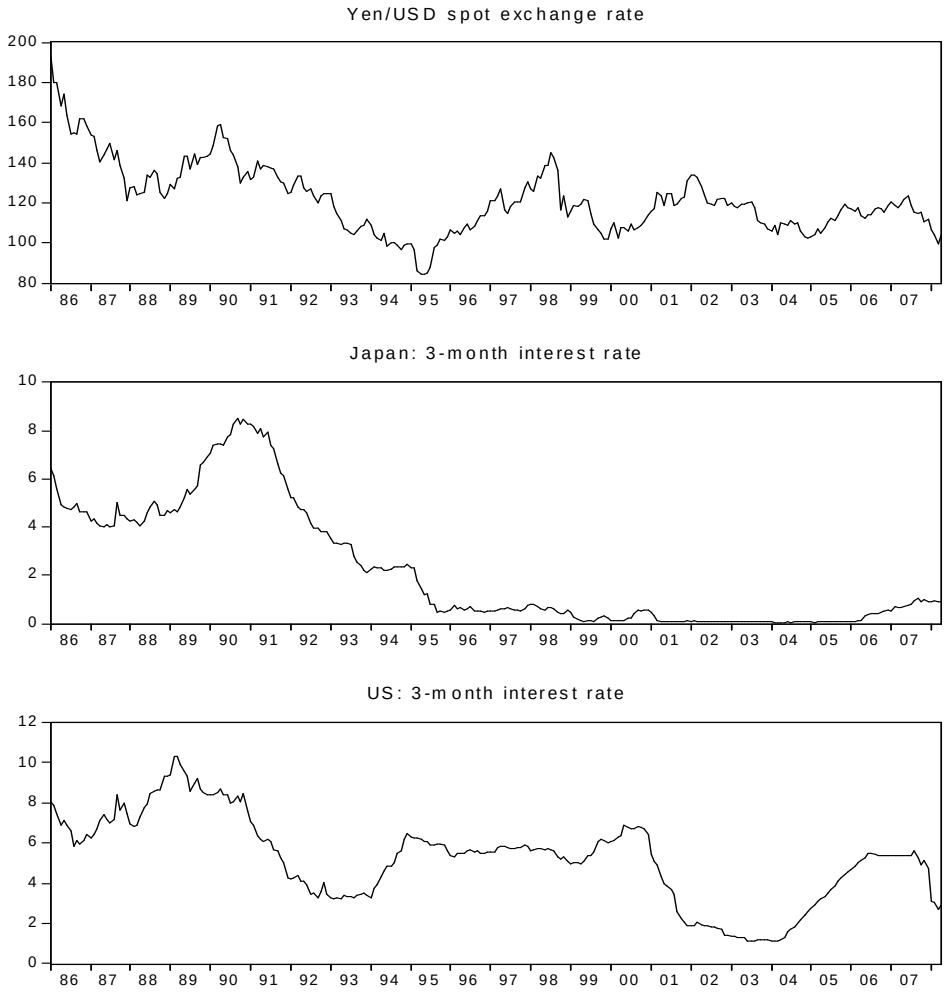
Estimates of the response vectors can be derived by combining the parameter estimates of the Markov-switching reduced model with the estimate of the matrix $\hat{\mathbf{A}}_i$, obtained through the identification scheme described above.

The precision of the estimated IRFs is gauged by employing standard bootstrapping techniques, taking into account that in a Markov-switching framework the bootstrapping is complicated by the presence of the hidden Markov chain determining the regime.

4. Data and Definitions

The analysis is carried out using monthly data from January 1986 to April 2008, with a total of 268 observations. In particular, I collected end-of-month data for the yen/dollar bilateral spot exchange rate and 3-month LIBOR interest rates. Exchange rates are yen-denominated and interest rates are expressed at annual rates. As a measure of exchange rate volatility I employed the realized volatility, calculated as the standard deviation of the daily returns within a month. All data are from Global Insight. Graphs of the exchange rates and interest rates are shown in Figure 1.

Figure 1: Japan and US: Exchange Rates and Interest rates



Let $r_{nt} \equiv s_{t+n} - s_n$, where s_t is the logarithm of the yen exchange rate, defined as the price of one US dollar in units of Japanese yen and s_{t+n} is its realization at time $t+n$. Therefore, r_{nt} can be interpreted as currency returns.

As a proxy for carry trade activity I use the net (short minus long) positions of speculators (non-commercial investors) on the Japanese yen futures market traded on the Chicago Mercantile Exchange (CME). The data are published in the weekly Commitments of Traders Report released by the US Commodity Futures Trading Commission (CFTC) and are available from 1986.[6] In my monthly analysis, I use the last available CFTC positions report for each month. A positive net position is economically equivalent to a currency trade where the US dollar is the investment currency and the Japanese yen is the funding currency, and, indeed, few speculators implement the carry trade by actually borrowing and trading in the spot currency market. However, it is worth noting that the position data should be interpreted with caution for a number of reasons. First, the distinction between commercial and non-commercial traders might not be sharp: while the latter are generally associated with speculative activity, it is possible that some commercial traders also take speculative positions; second, the trades identified as speculative may not result from carry trades; finally, a comparison with statistics from the BIS Triennial Central Bank Survey of Foreign Exchange and Derivatives Market Activity shows that only a small proportion of foreign exchange market activity is executed through exchanges.[7] Despite all the abovementioned caveats, the position data is the best publicly available data and it gives a sense of the direction of trade for speculators.[8]

Figure 2 shows that non-commercial short yen positions have been at record highs in the first half of 2007 and experienced a reduction in March and August of the same year. Most recent data show that net long non-commercial positions in the yen were established relative to the U.S. dollar in November 2007 and throughout the first four months of 2008. These speculative positions have matched changes in the U.S.-dollar/yen exchange rate quite closely, highlighting the role of carry trades as a likely contributor to the weakness of the yen.

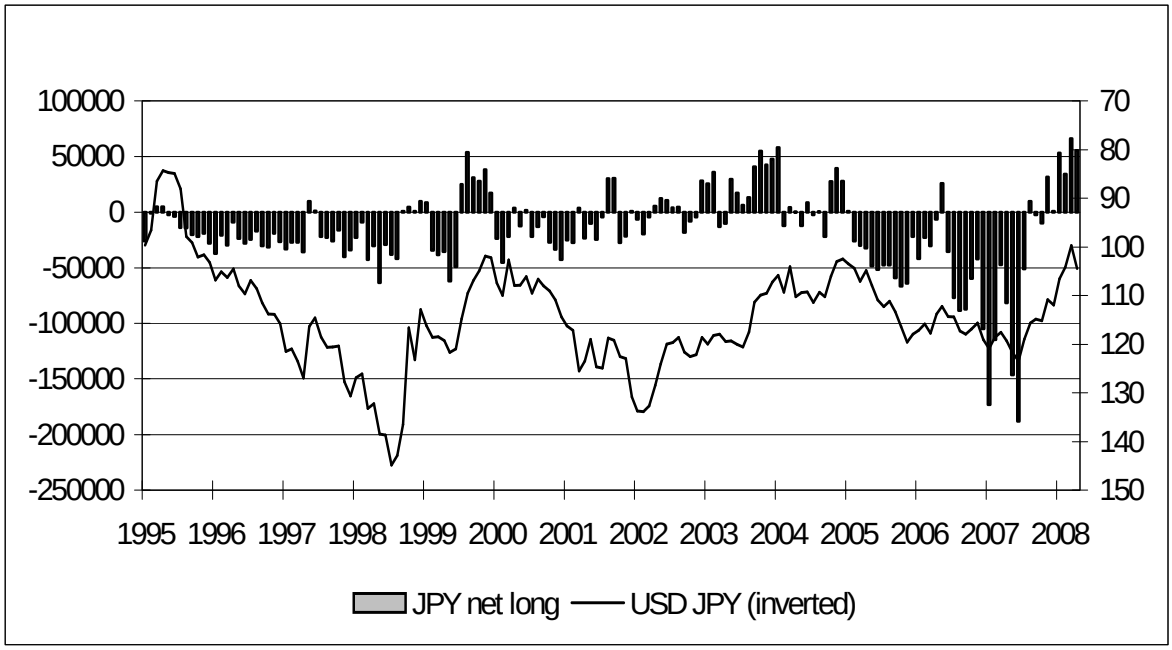
Interest rate differentials and exchange rate risk are the two main factors underlying the profitability of the carry trade. In particular, widening interest rate spreads between the funding and the target currencies increase the attractiveness of this strategy while increasing currency volatility, a proxy for the exchange rate risk, contributes to dampen it.

[6] The Commitments of Traders Report distinguishes commercial and non-commercial (speculative) positions in the International Money Market. In the case of yen positions, commercial positions are generally those taken for hedging currency exposure incurred through business operations, while non-commercial positions are those that generally reflect the speculative positioning of investors.

[7] For further details see Galati et al. (2007).

[8] Klitgaard and Weir (2004) make use of weekly net position data on futures traded on the CME and document a contemporaneous relationship between weekly changes in speculators' net positions and exchange rate moves.

Figure 2: Net Speculative Positions in the US Dollar/Yen



A popular indicator of the ex-ante profitability of the carry trade is the carry-to-risk ratio. This measure adjusts the interest rate differential by the risk of future exchange rate movements and it is defined as the interest rate differential (3-month interest rate differential between the high-yielding and low-yielding currencies) divided by the implied volatility of the respective bilateral exchange rate (a proxy for expected exchange rate movements).[9] By this measure, from 2004 to early 2007, yen carry trades could have been viewed as an increasingly profitable investment strategy by market participants.

The parsimonious set of variables described above defines the VAR model I estimate to shed some light on the dynamic relationship between the yen/dollar exchange rate and the carry trade.

5. Estimation Results:

5.1 Preliminary Analysis: Unit Root Tests and evidence from a conventional VAR

Prior to conducting the VAR analysis, I tested the order of integration of the variables included in the model by means of several unit root tests. The results of both the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, reported in Table A.1 in Appendix A, reject the null of non-stationarity, indicating that all the series are I(0). This allows to rule out the presence of cointegration.

Next, in order to get some initial feedback on the suitability of the rather parsimonious specification I chose as well as for comparison purposes with the results of the Markov-switching specification, I first

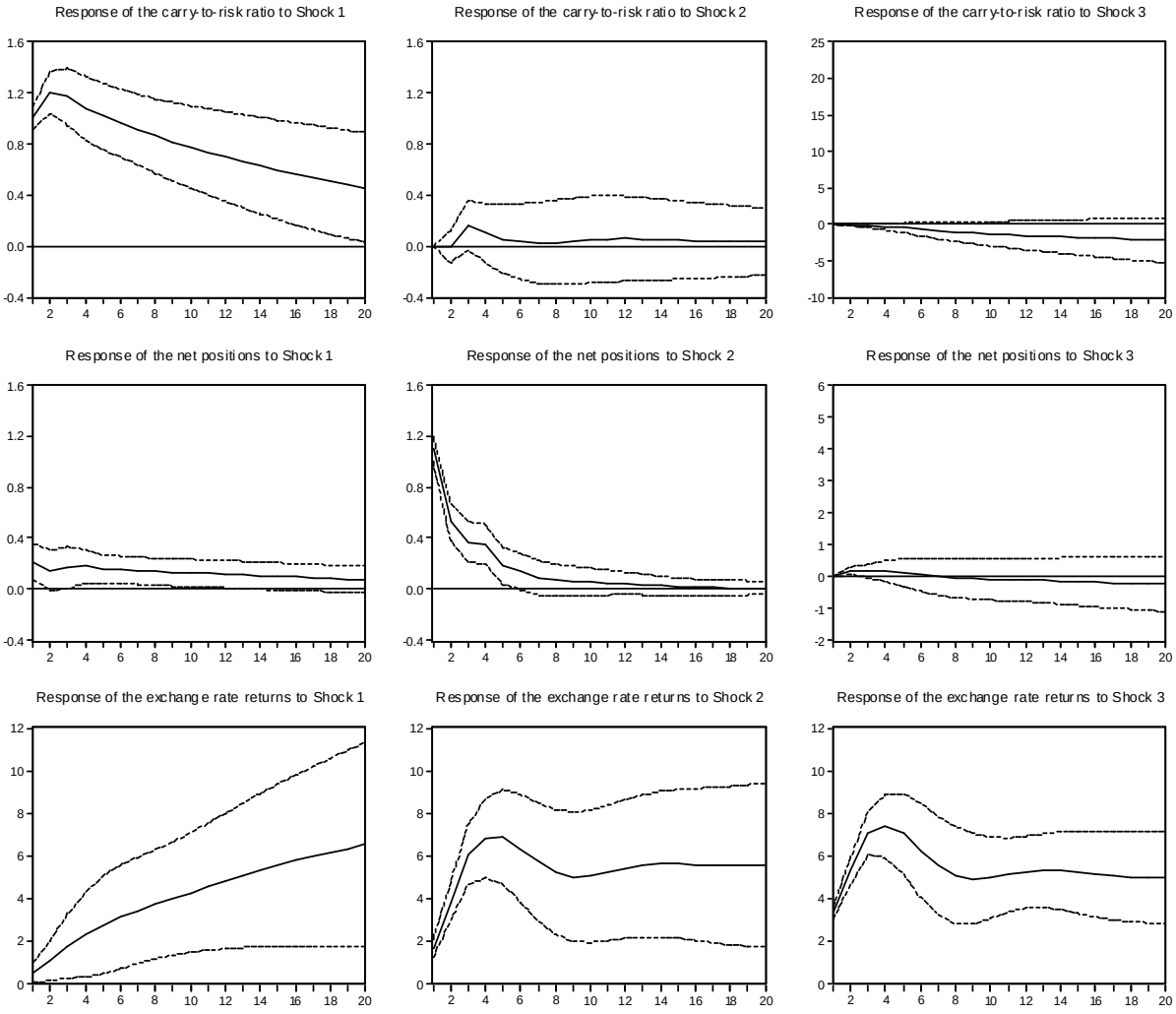
[9] Due to the lack of data for the implied volatility, I used a 3-month moving average of the realized volatility instead.

estimate a conventional 3-variable VAR model including (1) the carry to risk ratio, (2) the net short yen positions, (3) the exchange rate returns. The lag length was chosen to be three, in line with the results of the Hannan-Quinn information criterion.

In order to assess how and to what extent the endogenous variables in the model react to the fundamental disturbances, impulse response analysis is conducted. The impulse responses are identified by imposing a recursive structure on the model based on a Choleski decomposition with the ordering carry-to-risk ratio, net yen positions and the exchange rate returns. Such a structure relies on the assumption that shocks to the carry-to-risk ratio cause contemporaneous changes in the variables ordered below it but shocks to the other two endogenous variables do not affect the VAR innovation of the carry-to-risk ratio. Figure 1 displays the complete set of impulse responses over a 20-month horizon together with ±2 Monte Carlo standard errors.

Figure 1: Impulse Response Functions

(Conventional VAR)



Note: Each row shows the responses of one variable to all the shocks: from top to bottom, carry-to-risk ratio, short net positions, exchange rate returns; each column represents a shock: from left to right, carry-to-risk ratio, short net positions, exchange rate returns.

With regard to the carry-to-risk ratio shock (Shock1), a larger/smaller ratio, namely an increase/decrease in the attractiveness of the carry trade strategy, is expected to boost/dampen the net yen positions. Moreover, an higher/lower carry-to-risk ratio is expected to cause a depreciation/appreciation of yen against the dollar, via the carry trade channel. Panels 2 and 3 in the first column of Figure 1 confirm the expected effects and the statistical significance of the response of the exchange rate returns to Shock 1. The significance of the response of the net positions is less clear to assess: in particular, the effect is only significant in the first month and between the fourth and the twelfth month. It is worth noticing that although no root lies outside the unit circle and therefore the VAR satisfies the stability condition, convergence problems in the responses to Shock 1 arise from the relatively high persistence exhibited by the series of the carry-to-risk ratio (stemming from the dynamics of the interest rate differential). Such slowly decaying impulse responses have been observed in similar empirical studies in the literature, e.g. Castren, Osbat and Sydow (2006) and Froot and Ramadorai (2005). Other studies (e.g. Nishigaki (2007)) use first differences of the interest rate differential, to possibly circumvent this problem but the outcome of such specification is clearly more difficult to interpret.

In order to describe the consequences of the unwinding of the yen carry trade, it is interesting to focus on the impulse response of the exchange rate returns to shock in the net short yen positions (Shock 3), shown in the second panel of the last row of Figure 1. The graph reveals that positions shocks have a significant impact on the yen/USD exchange rate. In particular, an increase in the volume of yen carry trades will cause a sharp and persistent depreciation of the yen against the dollar. This implies that an unwinding would generally lead to a depreciation of the higher-interest currency (the dollar) with respect to the lower-interest rate currency (the yen).

5.2 Evidence from the MS VAR

The next step consists in the estimation of an unrestricted Markov-switching VAR, including (1) the carry to risk ratio, (2) net short yen positions and (3) exchange rate returns.[10] I assume the existence of two distinct regimes and allow intercepts, autoregressive parameters, variances and covariances to all switch between regimes. The lag length was chosen to be three, to ensure that the residuals are serially uncorrelated.

The estimation results support the following transition matrix for the two regimes.

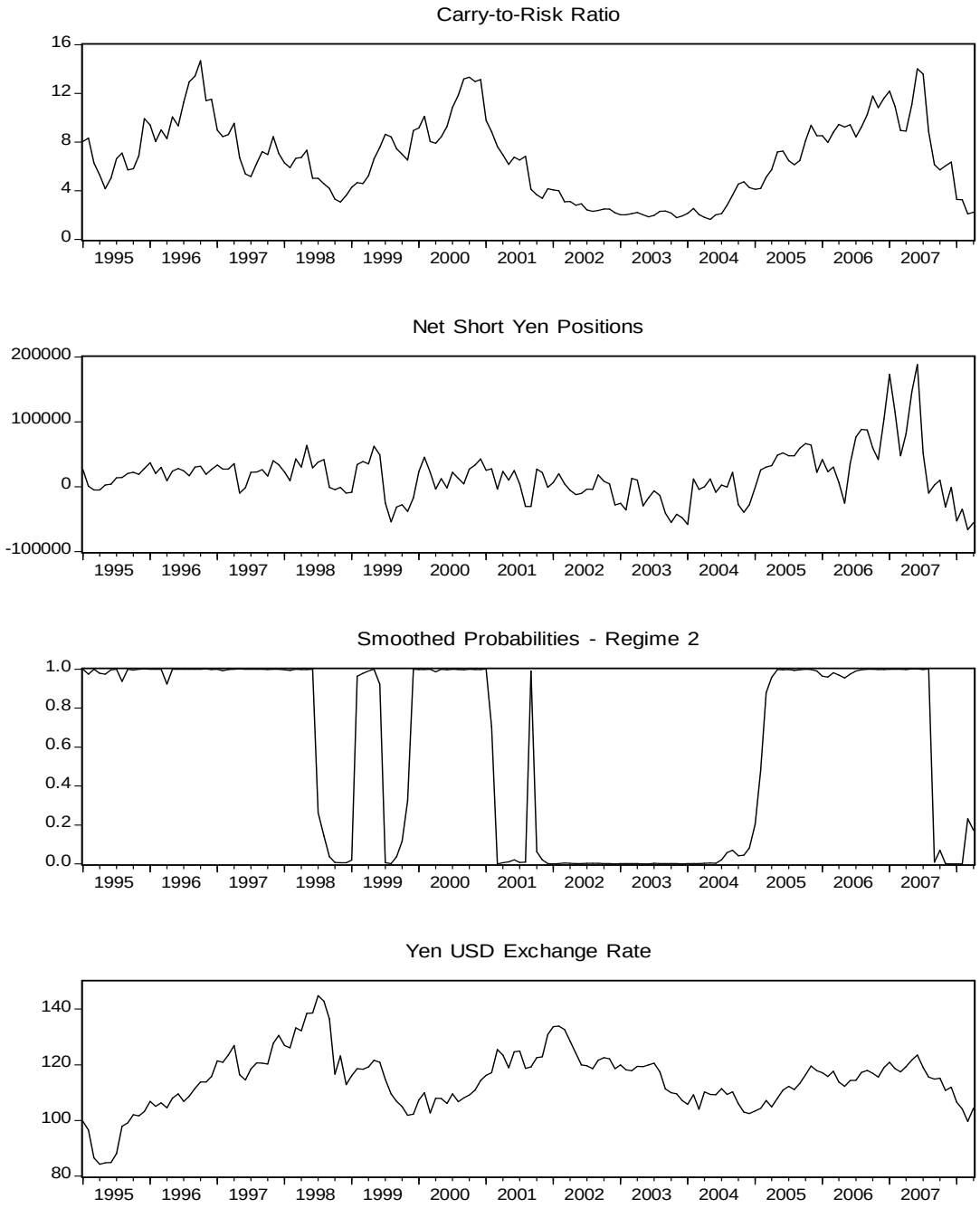
$$\hat{P} = \begin{bmatrix} 0.951 & 0.056 \\ 0.049 & 0.944 \end{bmatrix}$$

[10] Estimates are performed using the MSVARlib (Version 2.0) library for GAUSS by Benoit Bellone.

The regimes are estimated to be very persistent, with expected durations of approximately 20 and 18 months, respectively. Given that the estimated model allows all parameters to be state-dependent, a first step towards characterizing the regime is to observe the estimated smoothed probabilities of being in a given regime. Figure 2 plots the variables relevant in explaining the yen carry trade together with the smooth probabilities of being in regime 2: at a first look, the developments of the carry-to-risk ratio, net positions and bilateral exchange rate show some consistency with the regime classification tracked by the MS VAR and the correlation coefficients between the carry-to-risk ratio and the net positions with the estimated regime probabilities (panel 3) turned out to be rather high: 0.75 and 0.54, respectively. The timing of the regimes already gives a first indication about how they differ from each other. Whereas between the beginning of 1995 and late 1998 no regime switch has occurred, the regimes have been switching more frequently up to 2001: end of 1998, mid-1999 and early 2001. Between 2002 and the end of the sample two additional regime switches occurred: one at the end of 2004 and one in mid-2007. In the following I will try to relate the optimal inference of the hidden Markov chain followed by the regime to the episodes of yen carry trades that have been identified in the literature.

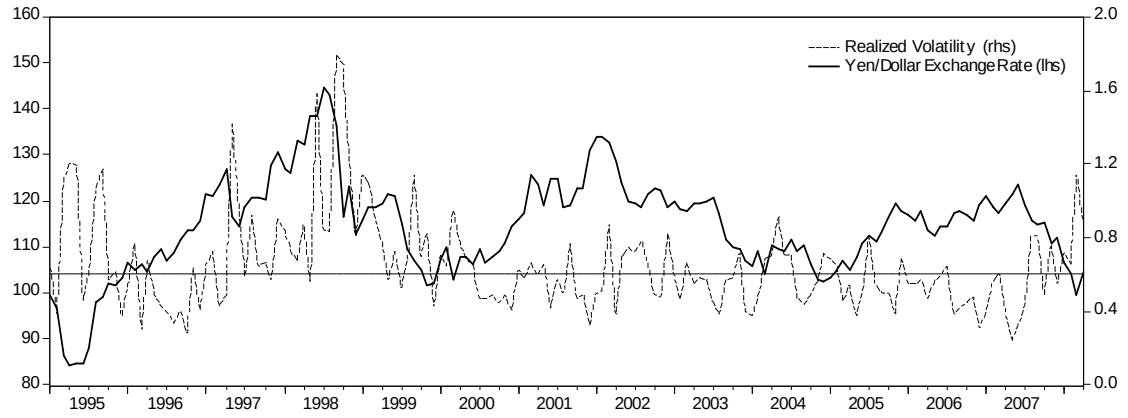
The period of dollar strength against the yen that had started in spring 1995 continued until summer 1998 (Figure 2, bottom panel). The weakening of the Japanese currency persisted despite the joint intervention of the U.S. Treasury and the Japan Ministry of Finance on the foreign exchange market in June 1998. Over three years, the dollar thus appreciated by 70 per cent against the yen, underpinned by continuing signs of robust economic growth in the US and persistent indications of weak growth in Japan. Following the Russian crisis, the US monetary authorities lowered interest rates in three steps between September and November 1998 and the dollar plunged heavily in two stages. With respect to the Japanese currency, the dollar depreciated by about 8 per cent between August 27 and September 7 and on October 7 and 8 took an unprecedented fall by loosing more than 13 per cent.

Figure 2: Net Short Yen Positions and Smoothed Probabilities



At the same time, the surge in the yen/dollar exchange rate volatility suggests that uncertainty about future movements in the yen/dollar rate rose substantially (Figure 3). Factors related to cyclical developments and other economic fundamentals do not appear to explain either the dollar's plunge or the unusual steepness of the dollar's fall against the yen occurred in early October 1998. Such developments may have been caused instead by technical factors unrelated to developments in the real economy but driven by specific market conditions (i.e. high currency volatility, wide US-Japan interest rate spread).

Figure 3: Yen/Dollar Exchange Rate and Realized Volatility



Note: The horizontal line refers to the January 1999 – April 2008 average of the realized volatility

One possible explanation is that in September and October highly leveraged hedge funds may have closed large short yen positions built up previously in an effort to take advantage of the low financing cost in that currency (the average interest rate spread was roughly 5 percentage points). The massive unwinding of these yen carry trades could have precipitated the dollar's decline. This episode of reversal of carry trade positions is captured by the model, as shown in the third panel of Figure 2. The strength of the yen and the intermediate position of the US dollar characterized the foreign exchange markets in 1999 and early 2000, primarily determined by the interaction of current and prospective relative cyclical positions, along with technical factors. The yen's sharp appreciation against the US dollar after June 1999 can to some extent be attributed to a narrowing of expected growth differentials between the two countries but technical factors might also help explain part of the exchange rate dynamics. In particular, the unwinding of yen carry trades as the yen trended upwards after June 1999 may at times have exacerbate the yen's strengthening. Salient features in the yen/dollar foreign exchange markets between January 2002 and the early months of 2004 were the continued depreciation of the US dollar and the several interventions of Japanese authorities to limit the yen appreciation. In this context, interest rate differentials re-emerged as an important factor behind exchange rate movements, with the US-Japan spread shrinking to its historical minimum. One mechanism through which current and prospective interest differentials influenced exchange rates was the carry trade, mechanism facilitating investors' search for yield. Based on the evidence from both market commentary and the Triennial Central Bank Survey, which shows that foreign exchange trading rose most strongly between banks and financial customers, carry trades appear to have underpinned the appreciation of a number of currencies against the US dollar and the yen (both regarded as funding currencies) in the course of early 2002-late 2004. Similarly, the unwinding of

such trades in reaction to changes in expected US policy rates in early 2005 may have contributed to the rebound of the dollar.

Over most of 2005 and the first months of 2006 interest rate differentials continued to be a major determinant of exchange rate movements, with the carry trade still being the most popular speculation strategy on the currency markets. The strengthening of the dollar against the yen during most of 2005 reflected the impact of the progressive tightening by the Federal Reserve on interest rate differentials.

Market commentary pointed to the yen as one of the major funding currencies in 2005, while the dollar switched from being a funding currency to a target currency as the tightening cycle of the US monetary authorities continued. During this period, as US interest rates increased steadily, borrowing in yen and investing in dollar-denominated assets appeared to be increasingly attractive.

In a context of historically low exchange rate volatility (Figure 3) and large US-Japan interest rate differential, the continuing build-up of carry trades was an important mechanism through which interest rate differentials played a role throughout the rest of 2006 and part of 2007 and arguably supported the appreciation of the target currencies such the US dollar. The carry-to-risk ratio (Figure 2, first panel), which measure interest rate differentials adjusted for the expected currency risk, highlights that for most of 2006 and early 2007 that carry trades funded by the yen were particularly attractive, underpinned by high interest rate differentials and low exchange rate volatility. Profitability fell in February 2007 in correspondence to a surge in the financial market volatility. Data on open positions in foreign exchange futures traded on the CME are consistent with yen carry trade volumes rising sharply in 2005 and 2006 but falling at the end of February 2007.

The yen/dollar exchange rate experienced a substantial increase in volatility in the second half of 2007. Consequently, carry trades were unwound, which led to some reversal of the previous exchange rate trends for the currencies involved. In particular, the yen did appreciate substantially starting in the latter half of 2007. As carry trades became less attractive (the yen/dollar carry-to-risk ratio fell substantially from July onwards, largely reflecting the spike in volatility), prevailing interest rate differentials became less of a focal point for market participants.

The regime classification obtained by means of the MS VAR (Figure 2, second panel) seems indeed to be consistent with the empirical evidence on carry trade episodes. In particular, the identified regime 2 comes close to a so-called “carry-trade” regime, whose timing is matches with the carry trade episodes identified in the literature. In the next paragraph, restrictions are imposed on the parameters estimates to derive a separate structural form for each regime, from which the regime-dependent IRFs can be calculated. IRFs can give valuable insight into the characteristics of regimes in a Markov-switching model.

5.3 Evidence from regime-dependent impulse response functions

In the following, I identify the impulse responses by imposing a recursive structure of the model, assuming that the fundamental disturbance to a variable has only contemporaneous effects on the variable itself and on the variable ordered below it. In the model I estimate the variables are ordered as follows: carry-to-risk ratio, net yen positions and the exchange rate returns. This ordering implies that: (a) the carry-to-risk ratio is exogenous to the other variables, (b) the investors´ speculative yen carry trade depends on the carry-to-risk ratio (c), the exchange rate return can react to all the other variables but cannot affect them within the same month.

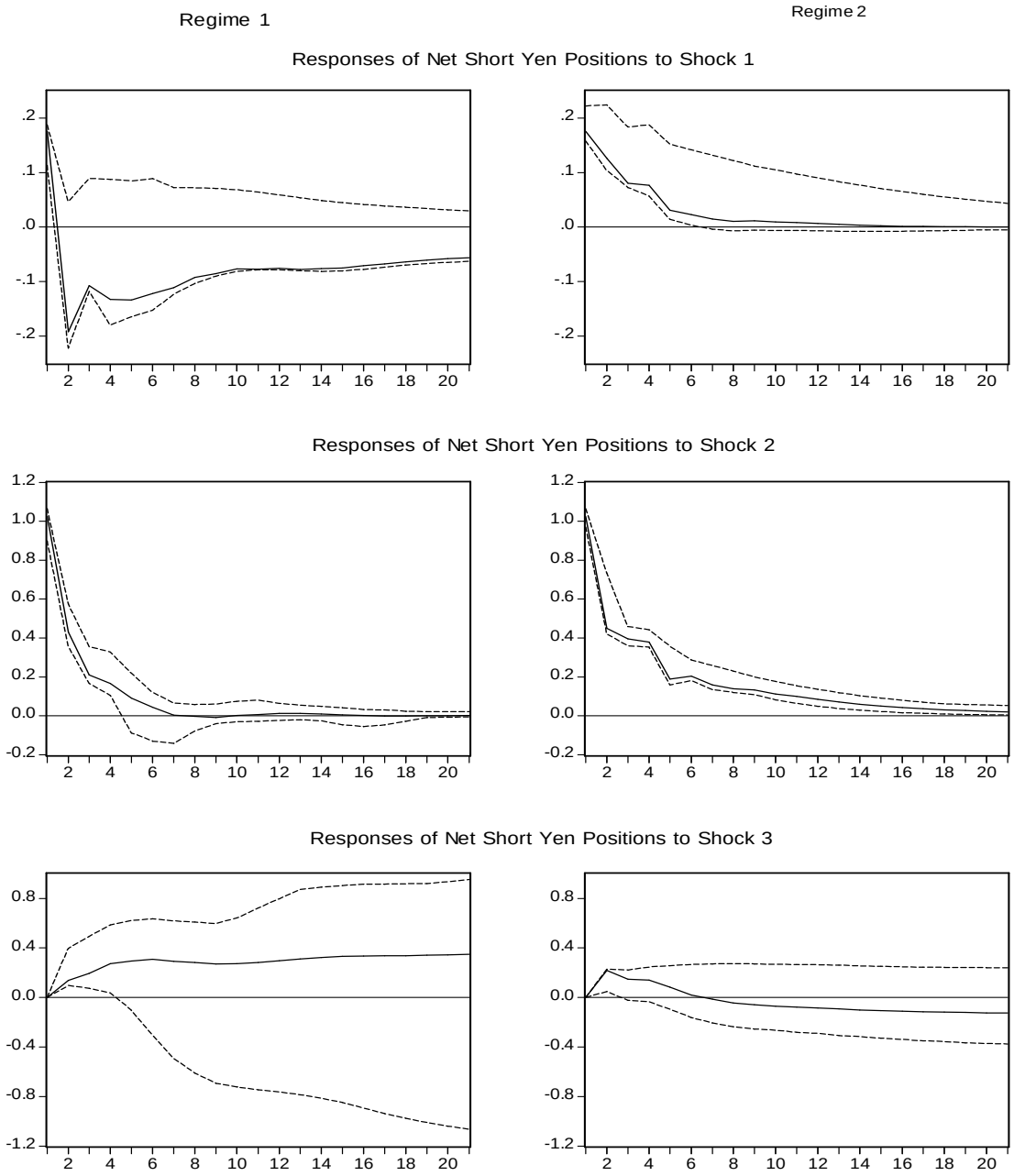
Two sets of regime-dependent impulse response functions together with the 95% (bootstrap) confidence bands[11] are displayed in Figures 4a and Figure 4b, where the left-hand column refers to regime 1 and the right-hand column refers to regime 2. Obviously, the impulse responses obtained from the conventional VAR are an average of those obtained for the two separate regimes, but a number of differences are noticeable across regimes in terms of both their magnitude and persistence. Figure 4a plots the responses of the yen positions to shocks on all the variables of the system. The conventional VAR results indicated that the speculative positions are positively affected by a fundamental shock in the carry-to-risk ratio but the significance of such impact is rather uncertain. A more comprehensive picture is indeed offered by the regime-dependent IRFs, which show that only when the system is in regime 2 (the "carry trade" regime), a shock in the carry-to-risk ratio has a positive effect on the net short positions in Japanese yen (row 1, Figure 4a), effect which remains significant for seven months before fading away, while when the system is in regime 1 an increase in the carry-to-risk ratio has no impact on the yen carry trade. Moreover, a positive shock to the net yen positions has a positive effect on the net yen positions in both states but such effect becomes insignificant four months after the shock when the system is in regime 1 while is persistent when the system is in regime 2 (row 2, Figure 4a). Finally, a yen depreciation leads to a slight increase in the carry trade volumes in both states, but such effect becomes insignificant three and four months after the shock in state 1 and state 2, respectively (row 3, Figure 4a).

In order to describe the consequences of the unwinding of the yen carry trade, Figure 4b plots the responses of yen/UDS exchange rate returns to shocks on all the variables of the system. In line with the results of the conventional VAR an increase in the yen carry trade leads to a persistent depreciation of the yen against the dollar but both the magnitude and the timing of the responses differ across states. In particular, after the fourth month following the shock, in regime 2 the depreciation of the yen is stronger and more persistent then in regime 1, where the IRF becomes insignificant 9 months after the shock (row 2, Figure 4b).

[11] The 95% confidence intervals are constructed by means of bootstrap simulation in order to account for fat tails, skewness and other non-Gaussian features of the distribution of the regime-dependent impulse responses. In this context, it would not have been appropriate to calculate the error bands by ± 1.96*(standard error) because this is an approximation of the 0.025 and 0.975 quantiles of the standard Gaussian distribution only.

Figure 4a: Responses of the Net Short Yen Positions

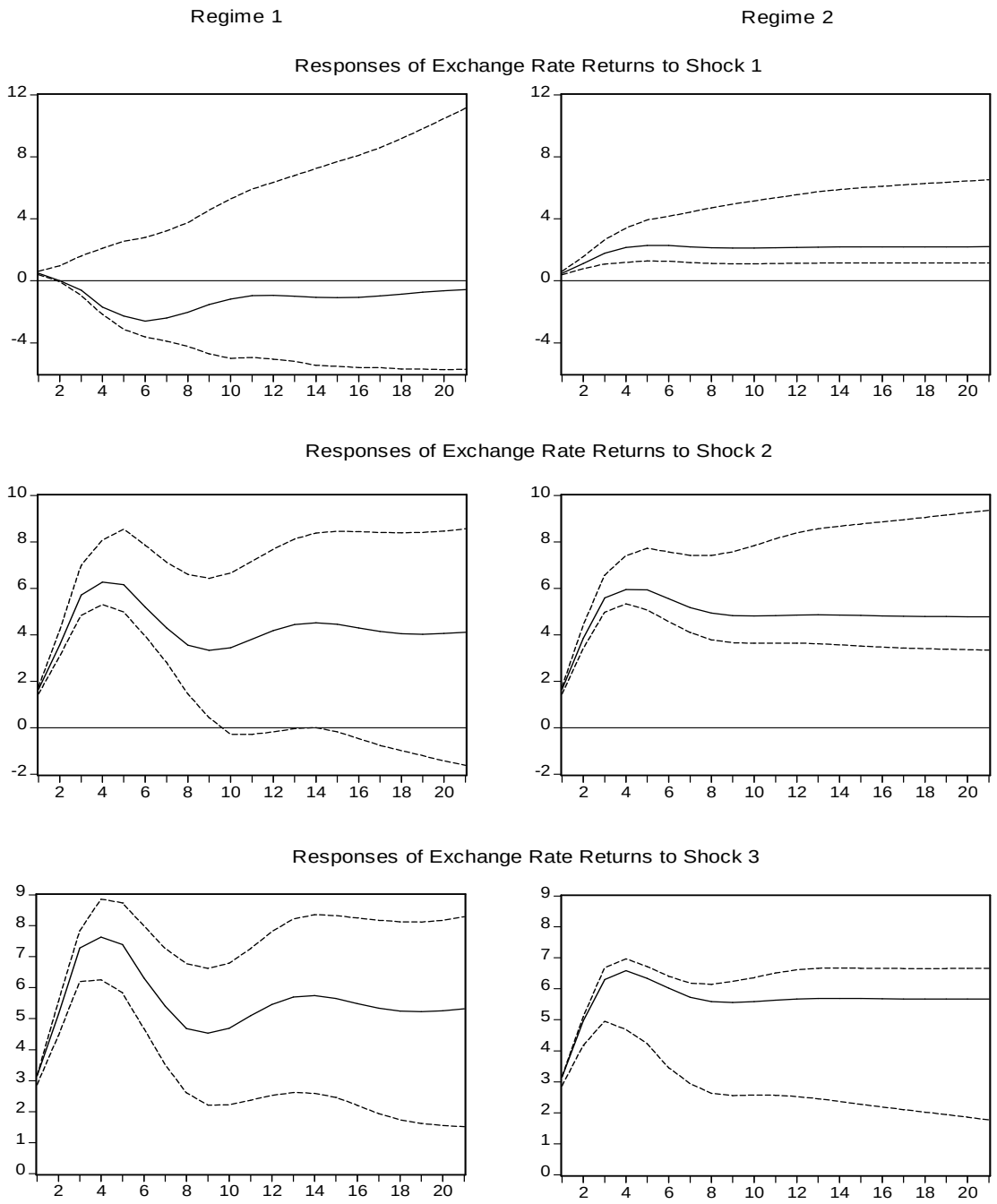
(MS VAR)



Note: Each row represents a shock: from top to bottom, carry-to-risk ratio, short net positions, exchange rate returns; each column represents a regime.

One last piece of evidence can be gained by looking at the responses of yen/USD exchange rate returns to shocks on the carry-to-risk ratio. Again, the evidence from the conventional VAR showed a positive and persistent effect of shocks to the carry-to-risk ratio to the yen/USD exchange rate but additional insight can be gained looking at the regime-dependent IRFs. The first row of Figure 4b shows that the yen significantly and persistently depreciates after a positive shock to the carry-to-risk ratio when the system is in regime 2 while there is no significant effect when the system is in regime 1.

Figure 4b: Responses of the Yen/USD Returns
(MS VAR)



Note: Each row represents a shock: from top to bottom, carry-to-risk ratio, short net positions, exchange rate returns; each column represents a regime.

In other words, a rising carry-to-risk ratio, which in turn reveals an increase in the attractiveness of carry trades, leads to a significant depreciation of the yen only when the system is in the "carry trade" regime.

To sum up, these findings validate the usefulness of a non-linear approach to shed further light on the dynamic relationship between exchange rates and carry trade.

The estimated MS VAR allows to distinguish phases in which the carry trade strategy might be profitable from phases in which such a strategy might not be profitable is not and models the relationship between endogenous variables and fundamental disturbances accordingly. The evidence provided is in line with the notion that the carry trade unwinding will have a significant impact on the exchange rate market by causing a significant and persistent appreciation of the funding currency with respect to the target currency.

5.4 Disentangling the effects of interest rate spread and volatility: evidence from a small probit model

The aim of this section is to explore the relationship between the regime classification identified by the MS VAR and the variables included in the model. Given the discrete nature of the dependent variable, the regime classification, which can only take on values of 0 (for regime 1) and 1 (for regime 2), a simple linear regression of the endogenous variable on the set of regressors is not appropriate. Instead, I adopt a probit specification, designed to handle the specific requirements of binary dependent variables. In a probit model, the dependent variable may take on only two values — might be a dummy variable representing the occurrence of an event. The interest lies in modelling the probability of observing a certain event, which, in the context of this paper, is the materializing of the "carry trade" state. Here the (binary) dependent variable is constructed on the basis of the smoothed probabilities estimated by means of the MS VAR. In particular, being Pr(s(t)) the smoothed probabilities of being in State 2 (the "carry trade" state), the endogenous variable of the probit model, y_i, takes value one when $\Pr(s(t)=2|I(t)) > 0.5$ and zero otherwise.

I modelled the probability of the system of being in the "carry trade" regime on two different sets of explanatory variables: the first one includes the carry-to-risk ratio and the exchange rate returns only (Specification 1), the second one includes the interest rate spread, the exchange rate volatility and exchange rate returns (Specification 2). The latter specification disentangles the carry-to-risk ratio into its two components aiming at shedding further light on the impact of such variables on the regime classification. The estimation results of both specifications are displayed in Table 1.

The LR statistic tests the joint null hypothesis that all slope coefficients except the constant are zero. This statistic, which is used to test the overall significance of the model, clearly rejects the null hypothesis in both specifications.

Turning to the interpretation of the coefficient values, in Specification 1 the carry-to-risk ratio has significant explanatory power with respect to the regime classification while the exchange rate returns have not. Moreover, the sign of the β_j coefficient determines univocally the direction of the effect of a change in each regressor x_j. In Specification 1, the positive value of the carry-to-risk ratio coefficient implies that increasing carry-to-risk ratio, hence higher attractiveness of carry trades, will increase the probability of being in the "carry trade" state. Specification 2 identifies a significant relationship

between all the regressors and the probability of being in State 2. Moreover, the negative value of the exchange rate volatility coefficient implies that increasing volatility will significantly *decrease* the probability of entering the "carry trade" state. On the other hand, the positive interest rate spread coefficient implies that a widening differential between US and Japan will significantly increase the probability of being in the "carry trade" regime.

Table 1: Probit models for the regime classification of State 2

(Sample: April 1986 – April 2008)

	Specification 1	Specification 2
Constant	-2.63***	-1.81***
	(0.318)	(0.372)
Carry-to-risk ratio	0.52***	
	(0.058)	
Interest rate spread		0.81***
		(0.085)
Exchange rate volatility		-1.30***
		(0.472)
Exchange rate returns	0.028	0.04**
	(0.018)	(0.018)
Log Likelihood	-76.010	-0.302
LR statistic	214.8910	206.609
Prob(LR statistic)	0.000000	0.000000

Notes: The entries in brackets are standard errors. A significant level of 10%, 5% and 1% is presented by *, ** and ***, respectively. The dependent variable is the probability of being in the "carry trade" regime.

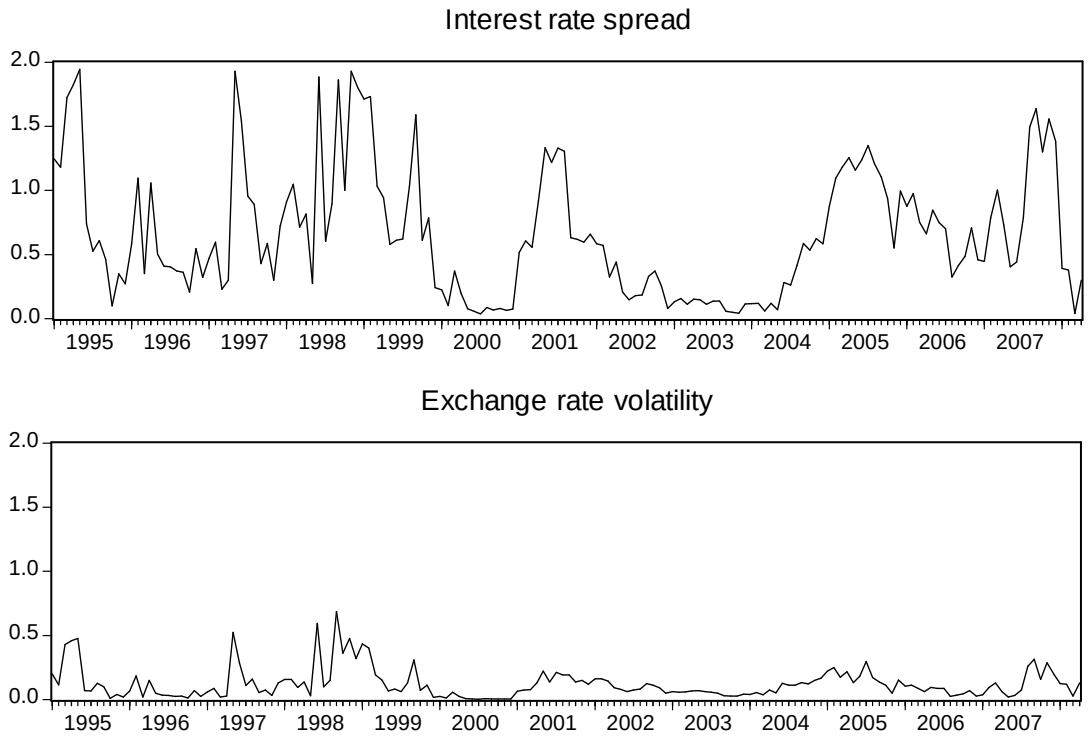
These results further validate the notion that the attractiveness of carry trades is positively affected by increasing interest rate spreads and negatively affected by the risk of future exchange rate movements, where this risk here is proxied by the realized volatility of the yen/USD exchange rate.

In a probit model, the effect of marginal changes in one regressor, x_j, on the conditional probability is a nonlinear functions of both the parameter estimates and the levels of the explanatory variables. Consequently, it cannot be inferred directly from the parameter estimates and is calculated as follows:

$$\frac{\partial E(y_t | x_i, \beta)}{\partial x_{ij}} = f(-x_i' \beta)\beta_j \tag{7}$$

where $f(x) = dF(x)/dx$ is the density function corresponding to Φ, the cumulative distribution function of the standard normal distribution, x is a vector of regressors and β is a vector of estimated coefficients. Figure 5 shows the marginal effect of the interest rate spread and exchange rate volatility calculated on the basis of the estimation results of Specification 2.

Figure 5: Marginal effects on the conditional probability



Two additional pieces of evidence can be drawn from Figure 5: first, throughout the whole sample period the impact of changes in the interest rate spread on the conditional probability of being in the "carry trade" state is twice as strong as the impact of changes in exchange rate volatility; second, the marginal effect of the realized volatility increases in correspondence of episodes of high exchange rate volatility (e.g. early 1995; 1998; mid 2007) indicating that the weight of the exchange rate risk on speculative decisions becomes higher in periods featuring high exchange rate market volatility.

6. Concluding remarks

The UIP theorem has had very little empirical support over the past 25 years. Moreover, it has been shown that high-rate currencies have tended to appreciate and low-rate currencies to depreciate, the reverse of theory. The failure of UIP has been no secret to participants in currency markets, where the carry trade (which is essentially a bet against UIP) has become a very popular investment strategy. These trades involve simultaneously going short the funding currency (a low-rate currency, e.g. the Japanese yen) and long the target currency (a high-rate currency, e.g. the US dollar) typically through the derivatives market. They are profitable as long as the gains from interest rate differentials are not offset by exchange rate movements. Consequently, they are sensitive to increases in exchange rate volatility. The investors involved are often highly leveraged, and could be forced to unwind positions very quickly in response to changing market conditions. The effect of the reversal of carry trade

positions might have a large impact on both exchange rates and on exchange rate volatility but such impact is hard to predict and depends, inter alia, on the speed with which these positions are closed. In some cases, the gradual unwinding of carry trades caused visible changes in exchange rates without a sizeable impact on short-term volatility.

To take into account that the carry trade strategy is profitable only when particular market conditions are fulfilled, i.e. only as long as the gains from interest rate differentials are not expected to be overwhelmed by exchange rate movements, this paper estimates a 3-variable MS SVAR model to shed some light on the dynamic relationships between interest rate differentials, exchange rate changes and carry trades. This non-linear setting has the attractive feature of allowing the system to distinguish between phases in which the carry trade strategy might be profitable and phases in which the carry trade strategy might not be profitable. Central to the MS VAR approach is the use of regime-dependent impulse response analysis, which traces out how fundamental disturbances affect the variables in the model dependent on the regime. In this study I use regime-dependent impulse response functions to assess (1) how and to what extent shocks to the interest rate differential and the bilateral exchange rate affect the yen carry trade; (2) the consequences of the unwinding of the yen carry trade on the dollar-yen exchange rate.

The main findings are as follows. First, the regime classification obtained by means of the MS VAR is consistent with the empirical evidence on carry trade episodes. In particular, the identified regime 2 comes close to a so-called “carry-trade” regime, whose timing is matches with the carry trade episodes identified in the literature. Second, only when the system is in the “carry trade” regime a shock in the carry-to-risk ratio has a positive and significant effect on the net short positions in Japanese yen. Such effect turns out to be insignificant when the system is in regime 1. Third, an increase in the yen carry trade generally leads to a persistent depreciation of the yen against the dollar but in the “carry-trade” regime such depreciation is stronger and persistent. Fourth, a rising carry-to-risk ratio, which in turn reveals an increase in the attractiveness of carry trades, leads to a significant depreciation of the yen only when the system is in regime 2. This shows that when technical factors, not directly related to fundamentals, play a role in exchange rate developments, speculative market conditions (i.e. the profitability of carry trades) have a significant impact and might exacerbate the ongoing trends on currency markets. Finally, the estimation of a small probit model, where the dependent variable was constructed on the basis of the smoothed probabilities of the MS VAR, further validates the notion that the attractiveness of carry trades is positively affected by increasing interest rate spreads and negatively affected by the risk of future exchange rate movements, where this risk here is proxied by the realized volatility of the yen/USD exchange rate.

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Appendix A: Unit Root Tests and Residual Analysis

Table A.1: Unit Root Tests

	ADF		PP	
Variable	Intercept (lag)	Intercept and Trend (lag)	Intercept	Intercept and Trend
Carry-to-Risk Ratio	-2.613* (5)	-2.597 (5)	-2.573*	-2.518
Net Positions	-5.825*** (1)	-5.841*** (1)	-7.812***	-7.926***
Exchange Rate Returns	-4.433*** (6)	-4.447*** (6)	-5.929***	-5.927***

Notes: ADF refers to the augmented Dickey-Fuller, PP to the Phillips-Perron unit root test. The lag length in case of the ADF test has been chosen according to the Schwarz Information Criterion, the bandwidth for the PP test according to Newey-West using the Bartlett kernel. A significant level of 10%, 5% and 1% is presented by *, ** and ***, respectively.

Figure A.1: Residuals of the conventional VAR

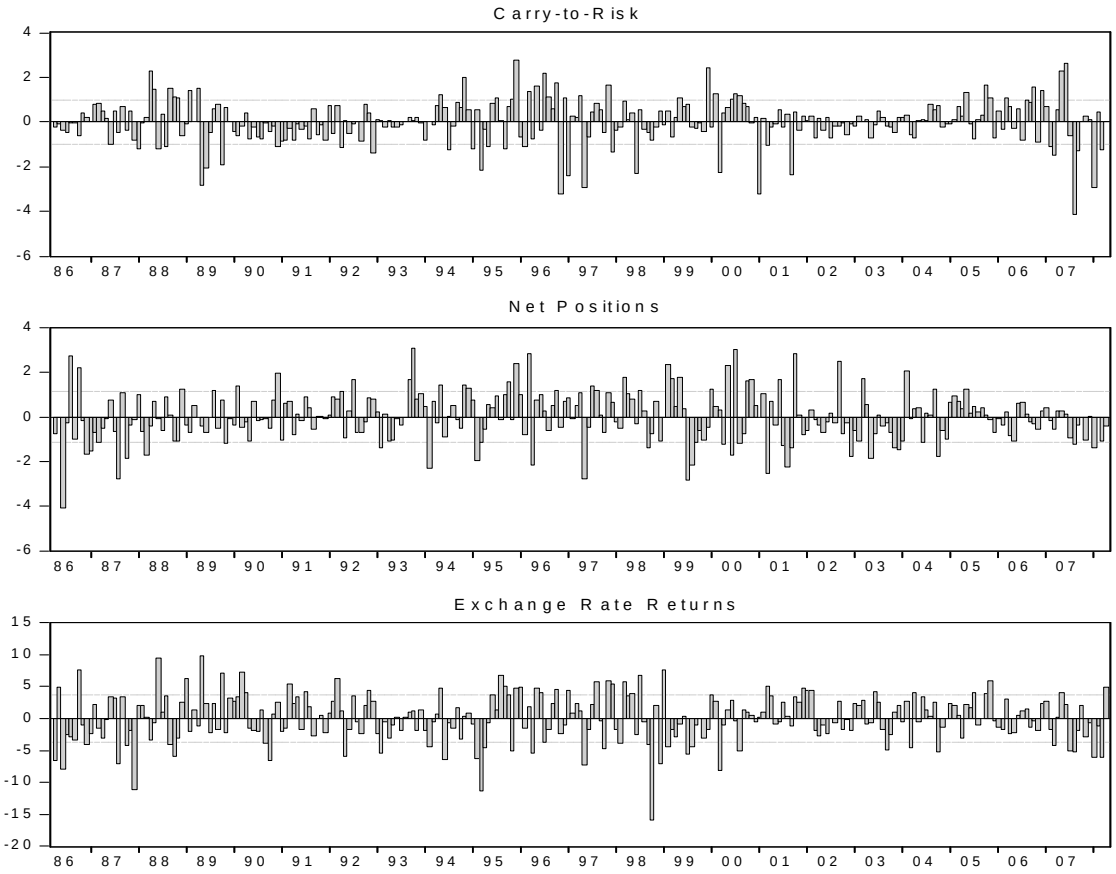
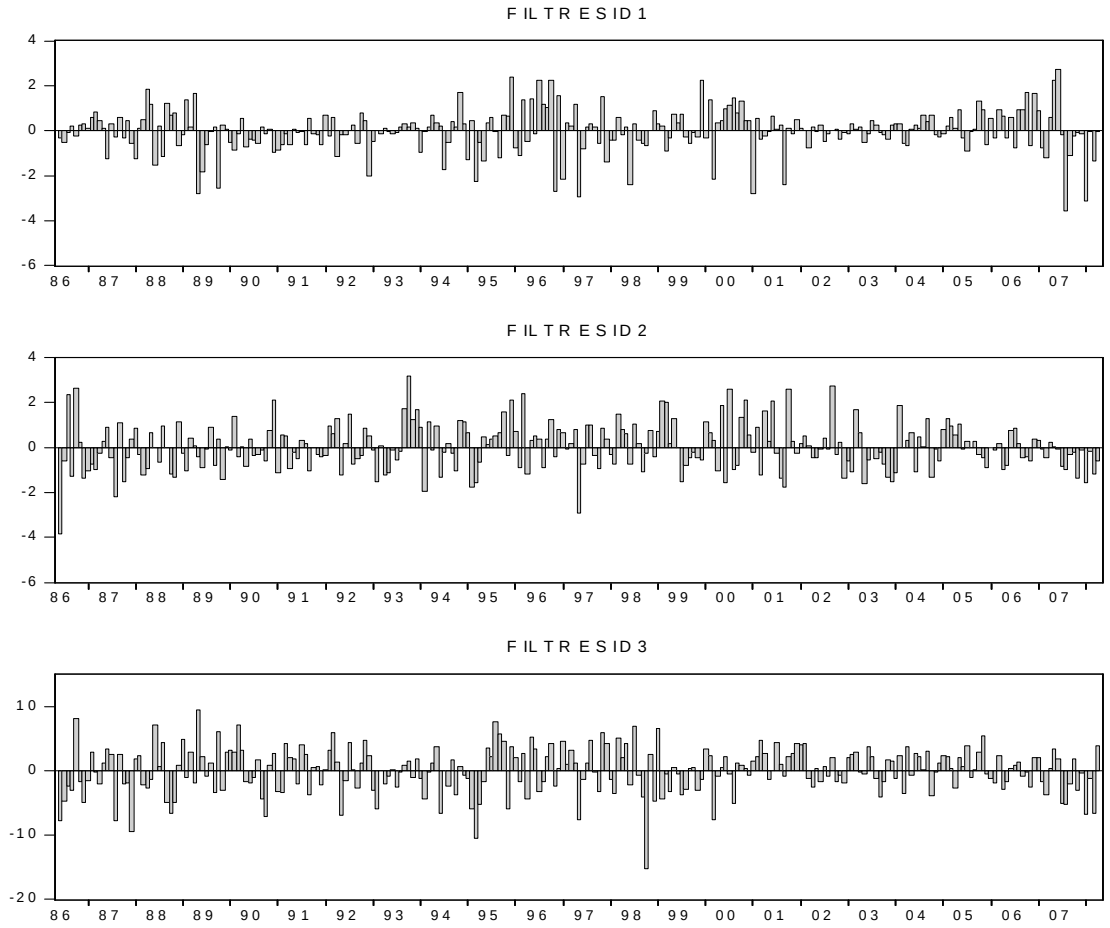


Figure A.2: Residuals of Markov Switching VAR



Appendix B: Bootsrapping

The precision of the estimated response vectors is assessed by means of standard bootstrapping techniques, which require the creation of artificial histories of the variables of the model and the submission of these histories to the same estimation procedure employed for the data. The artificial histories are obtained by replacing the parameters in the model with their estimated values, extracting residuals whose moments are determined by the estimated variance-covariance matrix, and then calculating the endogenous variables. By constructing a large number of artificial histories it is possible to make a bootstrapped approximation to the distribution of the estimated parameters.

In a Markov-switching framework, the presence of the latent variable, the hidden Markov-chain which determines the regime, makes the bootstrapping slightly more complicated. Prior to create the artificial histories, it is necessary to construct a history for the regimes, which is then used to continue with the endogenous variables. The full procedure consists of five steps for each history.

Step 1: A history for the latent variable, S_t, is constructed by recursively using the definition of a Markov process (Eq. (1) and (2)) and replacing the exogenous transition matrix with its estimated value, $\hat{P}$. For each period, *t*, a random number from a uniform [0,1] distribution is drawn and then compared with the conditional transition probabilities to determine whether there is a regime switch or not.

Step 2: A history for the endogenous variables is created. This is done recursively according to Equation (3), whose parameters are replaced by their estimated values. New fundamental residuals are then drawn from the normal distribution. Equation (3) is then applied recursively using the artificial regime history constructed in Step 1.

Step 3: The data from the artificial history are used to estimate a Markov-switching vector autoregression, which gives bootstrapped estimates of the parameters of the model, $\left\{\tilde{c}_i ; \tilde{\mathbf{B}}_{1i}, \ldots, \tilde{\mathbf{B}}_{pi} ; \tilde{\Sigma}_i \right\}$, for I = 1 ,…, M, the transition matrix $\tilde{\mathbf{P}}$, and the smooth probabilities $\tilde{\tilde{\xi}}_{it}$.

Step 4: Bootsrapped estimated of the matrices $\mathbf{A}_1$, …, $\mathbf{A}_m$ are obtained by applying the same identifying restriction as to the data.

Step 5: The bootstrapped estimates of the impulse response functions for each regime are derived by combining the new parameters $\tilde{\mathbf{B}}_{1i}, \ldots, \tilde{\mathbf{B}}_{pi}$ with the new estimates of the matrix $\mathbf{A}_1$, …, $\mathbf{A}_m$.

Applying the five steps described above for a sufficiently large number of histories yields a numerical approximation to the distribution of the original response vectors estimates. This distribution is the basis for adding confidence bands to the central estimate of the impulse response functions.