New Evidence of Currency Forward Premium Anomaly: Empirical Analysis with Multivariate Non-Linear Model

JEAN-MICHEL SAHUT*
Professor of Finance, Groupe Sup de Co Amiens & Cerege – University of Poitiers

MEHDI MILI
Assistant Professor, Modesfi – I.S.G.-Sousse & Cerege – University of Poitiers

The forward premium anomaly is generally formulated as the tendency for currencies with high interest rates to appreciate against currencies with lower interest rates, rather than depreciate as uncovered interest rate parity would suggest. Existing literature reports a puzzle about the forward rate over the future spot rate. The forward is often negatively correlated with the future value of the spot rate, which suggests that the forward rate predicts changes in the spot rate with the wrong sign[1].

The test of the forward premium anomaly consists in testing the hypothesis that forward exchange rate is an unbiased estimator of the correspondent spot exchange rate. The method generally used to test this anomaly comes to regress variations of spot exchange on lagged forward premium. That amounts to verify whether the slope coefficient of this regression equals 1 and whether the constant is null. Econometrically, this hypothesis has been widely contested.

The forward premium anomaly is related to empirical results appeared in the literature and support that the slope coefficient is generally different from 1 and sometimes negative. Departures from the forward rate unbiasedness hypothesis FRUH imply deviations from uncovered interest parity (UIP). Prior empirical research[2] in this area generally relies on linear frameworks in analyzing the properties of UIP deviations. Most studies support validity of the forward premium and suggest that spot and forward exchange rate dynamics are negatively related to lagged forward premium. Baillie and Kiliç (2006) suggest that linear estimation of the UIP condition may cause a forward premium bias when the true data generating process reveals strong nonlinearity.

Previously, taking into account non linearity and regime switching phenomenon has greatly modified methods that were used to explain forward premium anomaly. In fact, several reasons of non linearity are generally detected to justify deviations of exchange rate from the UIP conditions including transactions costs (*see*, Baldwin, 1992; Sercu and Wu, 2000; Obstfeld and Rogoff, 2000), central bank intervention (*e.g.* Mark and Moh, 2002; Moh, 2002), and the existence of limits to speculation (*e.g.* Lyons, 2001, pp. 206-220).

Based on these challenges to the use of linear models, the objective of this paper is to explore the contribution of multivariate non linear models to the analysis of forward premium anomaly on exchange market. To address this question, we present and estimate a multivariate logistic smooth-transition model (MV-LSTR). Our aim is to detect periods of occurrence of forward premium anomaly on exchange markets and to examine the dynamics of adjustment of exchange rate to the UIP and we measure the speed reversion to this relationship of equilibrium. Recent studies of Michael *et al.* (1997), Sarrantis (1999), Taylor and Peel (2000), Taylor *et al.* (2001) show the superiority of this representation compared to standard linear models. Our analysis is based on an empirical investigation of the behaviour of the EUR, UK Pound and YEN exchange rates relative to the US dollar.

To explain the forward premium anomaly, Baillie and Kiliç (2006), Sarno *et al.* (2006) propose a single equation smoothed transition model. This paper extends these two studies by modelling the joint dynamics of forward and spot exchange rates as functions of the forward premium. Our methodology expresses three main advantages. First, the joint modelling allows for possible interactions in the dynamics of spot and forward markets and also takes into account the effect of the expectations formation in the exchange markets. Thus, the joint distribution of the excess forward foreign exchange payoff and expected spot depreciation helps us to exploit possible extra information on the determination and the formation of the variables under consideration and leads to a better specification and better defined results. Second, the joint modelling may also reveal characteristics related to the exogeneity status of the forward premium and can thus indicate causality dynamics governing the formation of spot and forward exchange rates in the economy under consideration. Finally, our approach enables us to asses whether forward rates or spot rates are most efficient to reach more rapidly the adjustment to the uncovered interest rate parity equilibrium.

* Jean-Michel.Sahut@supco-amiens.fr

The rest of the paper is organized as follows. Section I illustrates the forward premium anomaly and presents limits of linear models. Section II introduces the MV-LSTR non linear model. The next section describes the data used and present results of Fama (1984) regression. Interpretation of estimation results of the MV-LSTR non linear model and its contribution to the explanation of the forward premium anomaly are discussed in section IV. This section studies also the adjustment of exchange rates to UIP. Finally, the last section concludes.

I. The forward premium anomaly and limits of linear models

The forward premium anomaly is one of the most important puzzles in international finance. The hypothesis which states that the forward rate is an unbiased predictor of the future spot rate is the subject of a large theoretical and empirical literature. The majority of related studies[3] rejects this hypothesis and shows that, contrary to rational anticipations, the relationship between forward and future spot exchange rate is negative. The test of this puzzle is generally performed by testing the covered interest rate parity (CIP) and the uncovered interest rate parity (UIP) conditions.

The covered interest rate parity (CIP) states that interest rate differentials perfectly forecast the spread between forward and future spot exchange rates. Formally this hypothesis implies that:

$$f_{t,k} - s_t = i_{t,k} - i^*_{t,k} \quad (1)$$

Where s_t denotes logarithm of spot exchange rate at time t. $f_{t,k}$ is the logarithm of the k-period forward exchange rate at time t. $i_{t,k}$ and $i^*_{t,k}$ are nominal interest rates available, respectively, for domestic and foreign assets of k-periods to maturities. The covered parity is generally validated in the literature[4].

Perfectly related to the CIP is the uncovered interest rate parity (UIP) that is generally perceived as a fundamental condition of exchange market efficiency. The UIP formulates the following principle: if structural large spread appears between interest rates associated to two different currencies, exchange rate movements rise to make the free risk investment in one currency equivalent to free risk investment of the same maturity in the other currency. Otherwise, it will be possible to realise unlimited gain with zero risk.

The empirical literature has largely checked whether the UIP work. A number of researchers have tested the UIP by verifying the following equation:

$$E_t(s_{t+k} - s_t) = i_{t,k} - i^*_{t,k} \quad (2)$$

Where $E_t(.)$ represents the expectation conditional on information available at time t. The Covered interest parity is directly related to the UIP and means that the following equations hold:

$$E_t(\Delta_k s_{t+k}) = f_{t,k} - s_{t,k} \quad (3)$$

$$E_t(s_{t+k}) = f_{t,k} \quad (4)$$

Equation (5) is known as the hypothesis of unbiased forward rate. First tests of the UIP and the unbiased hypothesis were based on estimating the following linear regression:

$$s_{t+k} = \alpha_1 + \beta_1 f_{t,k} + \varepsilon_{1,t+k} \quad (5)$$

Where $\varepsilon_{1,t+k}$ are zero means white noise process. Under the UIP hypothesis, the following restrictions must hold: $\alpha_1 = 0$ and $\beta_1 = 1$. Over the years, several researchers have examined regression (6) with various improvements in econometric approaches. Cornell, (1977), Frenkel (1977) and other researchers validate the FURH.

However, subsequent research of Meese and Singleton (1982), Doukas and Rahman (1987), and Baillie and Bollerslev (1994) confirm that exchange rates are not stationary. They pointed out a problem of spurious regression in testing the puzzle by showing with equation (6). These suggestions led researchers to consider the following equation expressed in first difference:

$$\Delta_k s_{t+k} = \alpha_2 + \beta_2 (f_{t,k} - s_t) + \varepsilon_{l,t+k} \quad (6)$$

The UIP holds if the expected exchange rate evolves in the same sense and in the same size with spread. The null hypothesis that is generally tested is $\beta_2 = 1$, $\alpha_2 = 0$ and the error term has a conditional mean zero. Thus, under the null hypothesis the forward rate is an unbiased predictor of the future spot exchange rate. A constant risk premium implies a significantly null constant without rejecting the fundamental hypothesis that differential interest rate reflects anticipations of exchange evolution.

The estimates of β obtained in the literature were usually negative and insignificantly different from zero. This negative estimate for β is the main feature of the forward rate anomaly; it implies that the more the foreign currency is at a premium in the forward market the less the home currency is predicted to depreciate.

The forward anomaly implies that an investor who enters a carry trade[5] is quite likely to make predictable profits from two sources: the interest rate differential between two currencies and the appreciation of the high-interest-rate currency that was originally bought at a forward discount.

Considerable resources have been devoted to "resolving" the forward premium puzzle. Some of this literature focuses on the failure of UIP itself by arguing that the forward premium includes a time-varying risk premium. However, the majority of these works suggest that a time-varying risk premium cannot account for the massive rejection of UIP found in the literature. Hence, the violations of UIP found in the literature are generally attributed to something other than a massive failure of UIP per se. This anomaly was largely explained in the literature by rejecting the hypothesis of linearity of the relationship between exchange rate dynamic and the forward premium.

The object of this paper is to use recent development of non linear models to explore the forward premium anomaly.

Various economic reasons for nonlinearity have been put forward over the years, notably, transaction cost (Baldwin, 1990; Dumas, 1992; Hollifield and Uppal, 1995; Sercu and Wu, 2000), Central bank intervention (Mark and Moh, 2002; Moh, 2002) and limit to speculation (Lyons, 2001).

Rationality of non linear relation between spot exchange rate and the forward one was largely explained in the literature by the hypothesis of limit to speculation. Namely, Lyons (2001) studies the impact of limits to speculation hypothesis to efficiency market tests and the non linear behaviour of deviation from UIP. He suggests that, under this hypothesis, investors only take up a currency trading strategy if this strategy is expected to yield a sufficiently large Sharpe ratio[6] that is higher than the one implied by alternative trading strategies, such as a simple buy-and-hold equity strategy. The Sharpe ratio can be interpreted as the expected excess return per unit of risk. This argument effectively defines a band of inaction where the forward bias does not attract speculative capital and, therefore, does not imply any glaring profitable opportunity and will persist until it generates Sharpe ratios that are large enough to attract speculative capital away from alternative trading strategies. Lyons (2001) argues that under the UIP hypothesis the Sharpe ratio of an exchange strategy becomes null. For a given forward premium, Sharpe ratios increase as the slope coefficient deviates from unity. Traders only allocate speculative capital to currency strategies if Sharpe ratios exceed a certain threshold, implying that β needs to deviate correspondingly far from unity to generate order flow. This logic suggests a range of trader inaction for β close to unity while capital could only be attracted if β over- respectively undershoots the bounds of this range.

Sercu and Wu (2000) derive, in a partial equilibrium model, an expression for the spot-forward relationship where, in the presence of transactions costs, expected exchange rate changes and forward premia are imperfectly aligned inducing nonlinearity in the spot-forward relationship.

In order to explain the forward premium anomaly on exchange market, we propose in this paper the extension of logistic smooth transition (LSTR) model proposed by Granger and Teräsvirta (1993) to a multivariate framework. The estimation of the model is based on the least square nonlinear technique which allows simple test of linearity and test of specification of models.

Sarno *et al.* (2006) and Baillie and Kiliç (2006) are the pioneers who have extended the model of Fama (1984)[7] in a nonlinear STR framework. These studies consider an univariate LSTR model. Their results confirm the nonlinearity of the relationship between exchange rate dynamics and the forward premium. Their developments allow for measuring adjustment speed to the UIP and explaining deviation by transaction cost and limit to speculation.

Sakoulis and Zivot (2000) and Guerra (2002) propose a generalisation of unvaried models testing the UIP to multivariate models. They investigate the relationship between the spot rate and the forward rate in a cointegration framework. They show the superiority of multivariate models compared to unvaried ones to explain the forward premium puzzle.

The present paper contributes to the relevant literature in that we re-examine the forward premium anomaly in a Multivariate smooth framework. The joint modelling of forward and spot exchange rates allows for possible interactions in the determination of prices of risk in both markets and also takes into account the effect of the expectations formation in the exchange markets. Thus, the joint modelling helps us to exploit possible extra information on the determination and the formation of the exchange rate under consideration and leads to a better specification and better defined results. In addition, the joint modelling may also reveal characteristics related to the exogeneity status of the variables and can thus indicate causation dynamics governing the formation of spot and forward exchange rates in the economy under consideration.

In this paper, we propose to generalise the traditional approach of Fama (1984) in a multivariate nonlinear smooth transition framework. The STR model introduced by Luukkonen, Saikkonen and Teräsvirta (1988), Luukkonen and Teräsvirta (1991) and Teräsvirta and Anderson (1992), is the extension of two regime Threshold Autoregressive model developed by Balke and Fomby (1997). Theses models are based on the idea that the economy can be situated in two different regimes. Yet, contrary to TAR models where the transition from one regime to another is brisk, STR method allows the regression coefficients to change smoothly from one regime to another. Moreover, in the STR model, the switching from one regime to another is endogenous and gives opportunity for an economic explanation of the non-linear behaviour to test whether that model also matches the empirical properties of the implied risk premium in exchange rate returns documented in Fama (1984).

Dumas (1994), Teräsvirta (1994) and Granger and Lee (1999) suggest that the main advantage in favour of STAR models is that changes in economic aggregates are influenced by changes in the behaviour of many different agents and that it is highly unlikely that all agents react simultaneously to a given economic signal. In financial markets, for example, with a large number of investors, each switching at different times (due to heterogeneous objectives), a smooth transition or a continuum of states between the extremes appears more realistic.

II. Multivariate nonlinear framework for forward premium anomaly

In this study, we make use of recent advances in threshold models in order to develop a multivariate nonlinear model to explain the relationship between exchange rate returns and the lagged forward premium. We look for a particular specification that explains the failure of the UIP and the occurrence of the forward premium anomaly. Through a particular specification we attempt to identify periods in which the UIP is verified. In this context, we develop a dynamic model with logistic function, related to Granger and Tearasvirta (1993) and Teasvirta (1994).

The smooth transition regression (STR) model is a non-linear time series model. It originated from Bacon and Watts (1971) who generalize the Quandt (1958) threshold regression model. Recent accounts include Granger and Teraesvirta (1993), Teraesvirta (1998) and Franses and van Dijk (2003). In its most basic form it is equivalent to a linear model with stochastically time-varying coefficients. Furthermore, contrary to the Markov-switching model, the STR model allows for endogenous regime switches, and therefore provides economic intuition for the non-linear behaviour.

We consider the following two regimes STR model:

$$\Delta f_{t+1} = \left[\alpha_{1f} + \beta_{1f}(f_t - s_t)\right] + \left[\alpha_{2f} + \beta_{2f}(f_t - s_t)\right] F_f(z_{ft};\gamma_f, c_f) + u_{f,t+1}$$
$$\Delta s_{t+1} = \left[\alpha_{1s} + \beta_{1s}(f_t - s_t)\right] + \left[\alpha_{2s} + \beta_{2s}(f_t - s_t)\right] F_s(z_{st};\gamma_s, c_s) + u_{s,t+1} \quad (7)$$

With $u_{f,t+1}$ and $u_{s,t+1}$ are two processes *i.i.d.* $(u_s, u_f) \sim N[0, \Omega]$. $F(.)$ is the transition function. With $F(.) \in [0;1]$, and it is continuous in the threshold transition variable z_i with $i = (f, s)$. Following Granger and Teräsvirta (1993), Teräsvirta (1994) and Jansen and Teräsvirta (1996) we consider a logistic Transition function as follow:

$$F(z_{it};\gamma,c) = \frac{1}{1 + \exp\left(-\gamma \prod_{j=1}^{m}(z_{it} - c_j)\right)} \quad (8)$$

with $c_1 \leq \ldots \leq c_m$

Where z_{it} is the transition variable which corresponds to the adjusted forward premia and is equal to $z_{it} = (f_t - s_t)/\sigma_{zt}$. The vector $c = (c_1, \ldots, c_m)'$ is m-dimension vector of location parameters. γ is a transition parameter determines the speed of transition between the two extreme regimes, with lower absolute values of γ implying slower transition. The values taken by the transition variable and the transition parameter γ determine the speed of reversion to UIP.

$\gamma > 0$ and $c_1 \leq \ldots \leq c_m$ are identifying restrictions. Empirically, it's enough to consider $m = 1$ or $m = 2$, since these two orders capture principal parameters variations. For $m = 1$, the model implies that the two extreme regimes are associated with low and high values of z_{it}. If $\gamma \to \infty$, $F(z_{it};\gamma,c)$ becomes an indicator function $I_{[Z_{it} > c1]}$ defined by: $I[A] = 1$ if event A occurs and 0 otherwise. In that case, the MV-LSTR model in (8) reduces to a two regimes threshold model of Hansen (1999). In case of $m = 2$, the transition function has as minimum $(c_1 + c_2)/2$ and attains the value 1 both at low and high values of z_{it}. Finally, for each order m, the transition function (9) will be constant when $\gamma \to 0$.

It's important to note that if $\lim_{z_t \to -\infty} F(z_t;\gamma,c)$, the function $F(.)$ will be in the lower regime and the model (8) becomes a standard linear Fama regression of the form:

$$\Delta f_t = \left[\alpha_{1f} + \beta_{1f}(f_t - s_t)\right] + u_{f,t+1}$$
$$\Delta s_t = \left[\alpha_{1s} + \beta_{1s}(f_t - s_t)\right] + u_{s,t+1} \quad (9)$$

While, if $\lim_{z_t \to +\infty} F(z_t;\gamma,c)$ the function $F(.)$ will be in the upper regime and model (8) becomes a different linear Fama regression with parameters exactly consistent with UIP:

$$\Delta f_t = \left[(\alpha_{1f} + \alpha_{2f}) + (\beta_{1f} + \beta_{2f})(f_t - s_t)\right] + u_{f,t+1} \quad (10)$$
$$\Delta s_t = \left[(\alpha_{1s} + \alpha_{2s}) + (\beta_{1s} + \beta_{2s})(f_t - s_t)\right] + u_{s,t+1}$$

Under the following restrictions $\alpha_1 + \alpha_2 = 0$ and $\beta_1 + \beta_2 = 1$, the lower regime occurs when the forward premium is less than the threshold level and gives rise to persistent deviations from UIP and thus a domain that is consistent with the forward premium anomaly. The outer regime is relative to high probability of the UIP condition being satisfied. In our set up the speed of adjustment towards parity of the UIP condition is allowed to depend on the size of the forward premium.

In order to generalize the STR model to allow for more than two different regimes we consider the following additive model.

$$IF(z_i,\gamma_i,c_i) = \sum_{j=1}^{r} \beta x F_j\left(Z_{it}^{(j)};\gamma_j,c_j\right) + u_{it} \quad (11)$$

Where $F_j(z_{it};\gamma,c)$ are logistic functions for $(j = 1,\ldots,r)$. If $m = 1$, $Z_{it}^{(j)} = Z_{it}$ and $\gamma_j \to \infty$ for $j = 1,\ldots,r$, the model (11) becomes a multivariate STR (MV-STR) with $r + 1$ regimes. So, the additive generalization can be seen as the generalisation of the multi-regime threshold model of Hansen (1999). Even the largest model to consider generally, is a two regime model (with $r = 1$ and $m = 1$ or $m = 2$), the additive model has an important role in evaluating the estimated model. In particular, the multi-regime model (12) is an alternative to test remaining nonlinearity. Evaluation of the MV-STR model will be discussed in section 3.2.

Building a MV-STR model requires a careful and systematic modelling strategy. The methodology available for univariate STR model can be readily extended to a multivariate framework. The setup of a MV-STR model consists of three steps: specification, estimation and evaluation stages.

The specification step includes tests of linearity and the selection of the transition variable z_{it}. The evaluation step integrates tests of parameters stability and no remaining linearity. Finally, we must choose the number of regimes to consider in the model, which means selecting r in equation (10). In the following subsections we discuss these steps in more detail.

II.1. THE MODEL SPECIFICATION: TEST OF LINEARITY

Testing linearity against ST(A)R constitutes the first step of the modelling procedure. The MV-LSTR proposed in equation (7) can be reduced to a linear model under the following hypothesis; $H_0 : \gamma_i = 0$ or $H_0' : \alpha_{2i} = \beta_{2i} = 0$ $(i = s, f)$. Following Luukkonen, Saikkonen, and Teräsvirta (1988) we test the linearity by testing the null hypothesis $H_0 : \gamma = 0$. After parameterisation, they propose the following auxiliary regression:

$$\gamma_{it} = \mu_i + \beta_0^{'*} x_{it} + \beta_1^{'*} x_{it} q_{it} + \ldots + \beta_m^{'*} x_{it} q_{it}^m + u_{it}^* \quad (12)$$

Where x_{it} is a vector of explicative variables which correspond in our case to the forward premium ($f_t - s_t$). The vectors of parameters $\beta_0^*, \ldots, \beta_m^*$ are the multiples of γ. $u_{it}^* = u_{it} + R_m \beta_1^{'} x_{it}$, , with R_m is the rest of Taylor expansion. In consequence, testing $H_0 : \gamma = 0$ in equation (8) is equivalent to testing the null hypothesis $H_0^* : \beta_0^*, \ldots, \beta_m^* = 0$ in equation (11). The null hypothesis can be adequately tested by the test of maximum likelihood multiplier (LM).

The LM statistic was derived by Gonzalez, Teräsvirta and Dijk (2005). Two remarks can be noted concerning this test. First, the test can be used to select the appropriate transition variable z_{it} in the MV-LSTR model. In this case, the test should be running for various transition variables and we select the one that highly rejects the linearity as transition variable. Second, the test can be applied to determine the appropriate order m of the logistic transition function in equation (8). Granger and Teräsvirta (1993) and Teräsvirta (1994) formulate the following sequence of tests to choose between $m = 1$ and $m = 2$. By using the auxiliary regression (10) with $m = 3$, we test the null hypothesis $H_0^* : \beta_3^* = \beta_2^* = \beta_1^* = 0$. If this hypothesis is rejected we test:

$$H_{03}^* : \beta_3^* = 0$$
$$H_{02}^* : \beta_2^* = 0 / \beta_3^* = 0$$
$$H_{03}^* : \beta_1^* = 0 / \beta_3^* = \beta_2^* = 0$$

We should select $m = 2$ if H_{02}^* is the most strongly rejected, otherwise we must select $m = 1$. For the reasoning behind this rule, see Teräsvirta (1994).

II.2. PARAMETERS' ESTIMATION

Once linearity is rejected against MV-STR, the second stage in building the specification is to select the appropriate transition variable and to estimate the parameters of the model. Granger and Teräsvirta (1993) and Teräsvirta (1994) propose to estimate the parameter vector $\theta = (\alpha, \beta, \gamma, c)$ in a MV-STR with the non linear least squared method.

II.3. MODEL EVALUATION

The evaluation of a MV-STR model is an essential part of the model building procedure. In this section we present two tests of misspecification developed in unvaried framework by Eitrheim and Teräsvirta (1996), namely, the test for parameter constancy over time and the test of no remaining nonlinearity. Li (1999) extends the application of these tests to multivariate models.

II.3.a. Test of non-constancy parameters hypothesis

The test of non-constancy parameter hypothesis is of major importance for multivariate models since the number of observation in multivariate models exceed those in unvaried models. This test implies the consideration of an alternative model with time varying parameters. Gonzalez, Teräsvirta and Van Dijk (2005) consider the following smoothed transition model with time varying parameters:

$$\gamma_{it} = \mu_i + (\beta' x_{it} + \beta' x_{it} F(z_{it}; \gamma_1, c_1)) + f(t; \gamma_2, c_2)(\beta' x_{it} + \beta' x_{it} F(z_{it}; \gamma_1, c_1)) + u_{it} \quad (13)$$

Where $f(t; \gamma_2, c_2)$ is an additional transition function defined by:

$$f(t; \gamma_2, c_2) = \left(1 + \exp\left(-\gamma_2 \prod_{j=1}^{h} (t - c_{2j})\right)\right)^{-1} \quad (14)$$

If $\gamma_2 = 0$, the function $f(t; \gamma_2, c_2)$ equal ½ for each t. so, the parameter of equation (10) will be constant. The test of non-constancy parameter entails the test of the null hypothesis $H_0 : \gamma_2 = 0$. Eitrheim and Teräsvirta (1996) deduce the LM statistic associated to the non-constancy parameter test and its Fisher distribution.

II.3.b. Test of hypothesis of non remaining linearity

The test of non remaining linearity can be performed in different ways. In our framework it's adequate to consider alternatively an additive MV-STR model with $r = 2$ or $r = 3$ regimes as alternative models. Thus:

$$\gamma_{it} = \mu_i + \left(\beta' x_{it} + \beta' x_{it} F_1(z_{it}^1; \gamma_1, c_1)\right) + \left(\beta' x_{it} + \beta' x_{it} F_2(z_{it}^2; \gamma_2, c_2)\right) + u_{it} \quad (15)$$

With transition variables z_{it}^1 and z_{it}^2 are not necessary the same. So, the null hypothesis of no remaining linearity in a two regime model is: $H_0 : \gamma_2 = 0$. This problem is more complicated by the existence of unobservable nuisance parameters under the null hypothesis. This complication is resolved by Gonzalez, Teräsvirta and Van Dijk (2005) by considering the Taylor expansion of model (8) around $\gamma_2 = 0$. The LM statistic of this test and the Fisher version are provided by these authors.

III. Data description and Fama (1984) regression

The data set used for our empirical analysis consists of daily spot exchange rate and 3-month forward exchange rate. We consider three exchange rates: EUR, UK pound and YEN exchange rates relative to the US dollar for the period from 4 January 1999 to 1 June 2007. We construct time series of spot exchange rate logarithm s_t and 3-month forward exchange rate logarithm f_t.

Table 1 reports description statistics of log spot and log forward exchange rate, forward premium $f_t - s_t$, depreciation rate $s_{t+1} - s_t$, and excess return $s_{t+1} - f_t$. Statistics show that forward premium, depreciation rate and excess returns are very low in mean with large standard deviations. The first order correlations of forward premium are very large and vary from 0.91 for the GBP to 0.99 for the EUR. This confirms the fact that forward premium is a highly persistent process. Yet, the depreciation rate shows weak serial correlation.

We first run the standard forward premium regression of Fama (1984) to test the stylized fact of the forward premium anomaly documented in the existing literature. The results of the regression analysis are summarised in

Table 1. Descriptives Statistics

	Moy	Std. Dev	Min	Max	Auto-Corr (1)
			EUR/USD		
s_t	0.0857	0.1440	– 0.1894	0.3125	0.9984
f_t	0.0872	0.1449	– 0.1854	0.3159	0.9997
$f_t - s_t$	0.0014	0.0038	– 0.0074	0.0073	0.9899
$s_{t+1} - s_t$	0.0000	0.0064	– 0.0687	0.0680	0.0274
$s_{t+1} - f_t$	– 0.0014	0.0077	– 0.0754	0.0643	0.1269
			YEN/USD		
s_t	– 4.7435	0.0622	– 4.9020	– 4.6205	0.9975
f_t	– 4.7346	0.0633	– 4.8976	– 4.6061	0.9987
$f_t - s_t$	– 0.0026	0.0037	– 0.0144	0.0132	0.9689
$s_{t+1} - s_t$	0.0008	0.0050	– 0.0175	0.0274	0.0302
$s_{t+1} - f_t$	– 0.0089	0.0083	0.1030	– 0.1107	0.0953
			GBP/USD		
s_t	0.5058	0.1029	0.3177	0.6960	0.9937
f_t	0.5032	0.1028	0.3134	0.6953	0.9978
$f_t - s_t$	0.0089	0.0045	0.0176	0.0058	0.9129
$s_{t+1} - s_t$	– 0.0004	0.0068	0.1030	– 0.0962	0.0947
$s_{t+1} - f_t$	0.0027	0.0057	0.0265	– 0.0169	0.0733

Table 2 with standard errors between parentheses. The estimations document the presence of the forward premium anomaly as suggested by previous research. We note a significant and a negative impact of the forward premium. The constant is close to zero and statistically non significant. The coefficients of determination R^2 are very low, which imply a problem of misspecification in the estimated regression.

Table 2. Estimation of the linear Fama (1984) regression $\Delta s_{t+1} = \alpha + \beta(f_t - s_t) + \varepsilon_{t+1}$

	α	β	R^2
EUR/USD	0.000179	– 0.08094	0.0024
	(0.2328)	(0.0247)	
GBP/USD	0.000075	– 0.01320	0.0001
	(0.8186)	(0.6847)	
YEN/USD	– 0.0304	– 0.04526	0.0011
	(0.7998)	(0.1205)	

IV. The forward premium anomaly in a MV-LSTR non linear framework

In this section we examine what implications our MV-LSTR model has on the forward premium puzzle and on explaining deviation from the UIP condition. In a first step we test the linearity by using the excess returns as transition variables[8]. Results of LM test fisher version for m = 1, 2 and 3 are presented in table 3.

For each exchange rate we find that the LM-F statistics are not significantly different from zero. Our results strongly reject the null hypothesis of linearity against the alternative non linear MV-LSTR model.

In next step, we apply the sequence of tests proposed by Granger and Teräsvirta (1993) and Teräsvirta (1994) to select the order m of the logistic function between m = 1 and m = 2. Results are reported in table 4. The hypothesis H^*_{02} is the most strongly rejected, so we select the order m = 1 to specify our transition function.

Table 3. Test of Linearity against STR model

	EUR/USD		GBP/USD		YEN/USD	
	LM	P-Value	LM	P-Value	LM	P-Value
M						
1	23.620	0.000	33.387	0.000	82.734	0.000
2	59.281	0.000	24.859	0.000	45.747	0.000
3	44.888	0.000	40.830	0.000	55.252	0.000

Before discussing results of estimations of the MV-LSTR model, we check whether equation (8) is an adequate characterization of the nonlinear features rendered by the data by looking at remaining linearity in order to choose the number of regimes r. Table 5 reports results of no remaining linearity and parameters constancy.

Our results reject the null hypothesis of no remaining linearity. We select the order r = 1 that specify a smoothed transition model with two extreme regimes. Results of parameters constancy test reported in the same table do not reject the null hypothesis of constant parameters with time.

Model (8) is very general since it allows for three regimes with different dynamics. Under the following restriction $\alpha_{i1} + \alpha_{i2} = 0$ and $\beta_{i1} + \beta_{i2} = 1$, the upper regime corresponds to the domain where the uncovered parity has high probability to be verified. The forward premium increases as the probability that the uncovered parity to be verified increases. Conversely, negative values or low values of the forward premium are associated with very stimulant regime for investor to speculate which induce the UIP equilibrium to be verified. This stance confirms arguments documented by theories explaining the forward premium with limits to speculation on exchange markets.

If our specification of exchange rate is an approximation of the uncovered parity of interest rate condition, then expected coefficient in the equation (5) of Fama (1984) can be statistically different from 1. In this case, the majority of realisations of forward premium move away from upper regime, and in consequence the forward premium has more chance to appear.

The parameter estimates of the MV-LSTR model under the restriction $\alpha_{i1} = -\alpha_{i2}$ and $\beta_{i1} = 1 - \beta_{i2}$ are reported in table 6. Standard deviations are reported between parentheses. Following Granger and Teräsvirta (1993) and Teräsvirta (1994, 1998), we standardise the transition variable by dividing it by the sample standard deviation of the transition variable. The transition variable is just the risk adjusted forward premium which corresponds to the Sharpe ratio. The consideration of the Sharpe ratio is of major importance to characterise the relationship between our theoretical approach and our empirical framework.

Our empirical results strongly reject the hypothesis linearity in the relationship between spot and forward exchange rates. In fact, the transition parameter γ appears significantly different from zero, except for the case of Japanese YEN where this variable appears insignificant in the equation of spot exchange rate variation. Parameters γ and c evidence that the transition from low to upper regimes is smooth but relatively rapid. The parameters γ express high values in spot markets than in future markets. This finding shows that spot market insures more rapid adjustment to the UIP equilibrium. The joint distribution of the excess forward foreign exchange payoff and expected spot depreciation, allows us to deduce that monetary authorities are held to intervene on the spot market to restore more rapidly the UIP equilibrium and to limit arbitrage opportunities on the exchange market.

It is important to note that estimated parameters β_{i1} and β_{i2} are correctly signed according to the hypothesis of limit to speculation. In fact, we note negative values of β_{i1} and large positive values of β_{i2}. With the exception for the Japanese YEN where we note positive value and almost null coefficient of β_{s1} against a low negative value of coefficient β_{f1}. Globally, the uncovered interest rate parity is verified when the transition function converge to its asymptotic of unity, $F(.) = 1$. These results imply, generally, that the forward anomaly appears for low or negative values of forward premium, while large forward premium is, generally, associated to the validation of the uncovered interest rate parity.

Table 4. Sequence of test for selection of *m*

	EUR/USD		GBP/USD		YEN/USD	
	LM	P-Value	LM	P-Value	LM	P-Value
$H^*_{03}: \beta^*_3 = 0$	26.363	0.078	13.117	5×10^{-4}	33.122	12×10^{-2}
$H^*_{02}: \beta^*_2 = 0 / \beta^*_3 = 0$	29.459	2×10^{-4}	13.135	2×10^{-6}	45.157	16×10^{-3}
$H^*_{01}: \beta^*_1 = 0 / \beta^*_2 = \beta^*_3 = 0$	46.741	3×10^{-6}	18.622	3×10^{-9}	47.920	24×10^{-6}

Table 5. Test of no remaining linearity and test of no constancy parameters

	EUR/USD		GBP/USD		YEN/USD	
	LM	P-Value	LM	P-Value	LM	P-Value
Test of no remaining linearity						
m						
1	0.344	0.335	1.128	0.852	1.724	0.835
2	1.022	0.273	1.677	0.754	1.385	0.364
3	1.429	0.450	1.254	0.256	1.037	0.229
Test of no constancy parameters						
m						
1	1.986	0.653	0.984	0.351	0.347	0.547
2	1.937	0.385	1.633	0.854	0.733	0.472
3	1.784	0.477	1.264	0.533	1.652	0.997

Moreover, high value of risk adjusted forward premium induces *F(.)* to have values close to 1 and to insure convergence to UIP. Conversely, if the forward premium is low or even negative, the transition function takes value close to zero inducing the forward premium anomaly on exchange markets. Results of LR ratio of the null hypothesis $\alpha_{i1} = -\alpha_{i2}$ and $\beta_{i1} = 1 - \beta_{i2}$, are also reported in table 6. We retain the validity of theses restrictions at 5% level of significance.

According to the limits to speculation hypothesis, for small excess returns the forward bias does not attract speculative capital, which can be more profitably to invest in alternative investment opportunities for the same level of risk. Our nonlinear model parsimoniously captures the behaviour on spot and forward exchange rate curves. Hence high values of the forward premium tend to push the transition function F (.) towards the neighbourhood of unity and towards the UIP condition holding. Conversely, when the premium on the US dollar is low, and sometimes negative, the transition function takes values in the neighbourhood of zero, which tends to be associated with the forward premium anomaly.

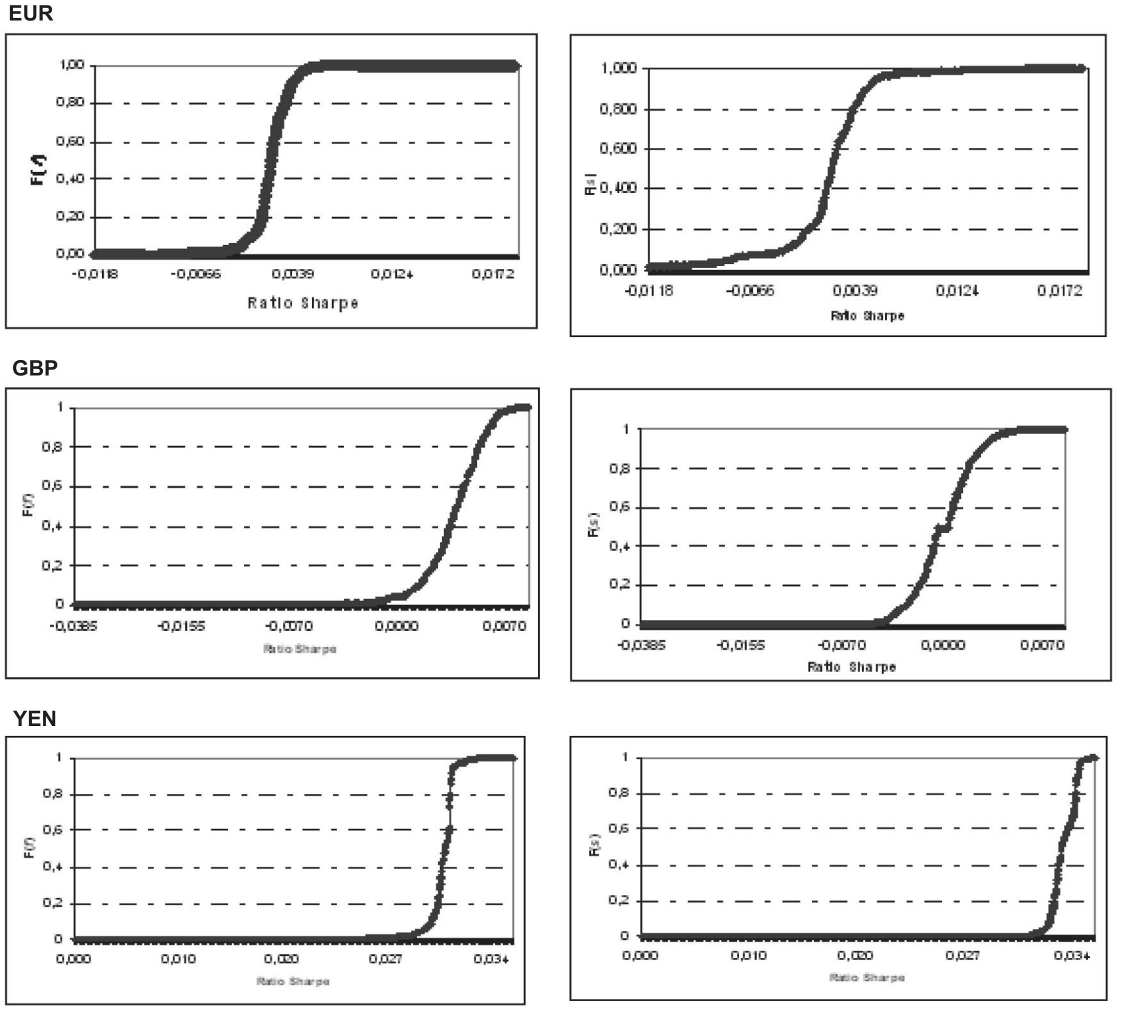
It is very important to determine through estimated MV-LSTR models the necessary forward premium threshold to see transition function in the upper regime. This information can be deduced from figure 1 in which we plot the transition function in step with the transition variable. The forward premiums of spot and forward exchange rate dynamics are almost identical for all countries. It resorts from the figure that The UIP is verified when forward premium approximately exceed 0.39% for the EUR, 0.70% for the GBP and 0.24% for YEN. Contrary, the forward premium appears when the forward premium is approximately lower than – 0.62% for the EUR, – 0.32% for the GBP and 0.27% for the YEN.

A clear majority of observations lie in either one of the extreme regimes, but there is also a number of them located in-between. For each exchange rates considered, observations between the two regimes are much fewer in forward rates dynamics equation than those associated with spot exchange rate dynamics. We, also, remark that the transition functions of forward exchange rate exert an important adjustment reversion effect to the UIP condition compared with the transition function of spot exchange rate. The adjustment speed depends on the size of the adjusted risk forward premium. These results seem consistent with arguments documented by the limit to speculation hypothesis.

The figure shows that for the GBP and the YEN, the majority of transition function observations are close to zero. We deduce that for these two currencies the majority of forward premium observations are lower than the necessary threshold to induce reversion to PNC. We conclude that forward premium is insufficiently attractive to push the transition function to take values close to 1 and to induce investors to change their positions on exchange market. In this case, dynamics of spot and forward exchange rates do not validate the PNC.

We note some uniformity of adjustment speed for the GBP and the YEN. Whereas, the speed adjustment of the EUR appears very slow. Results indicate that forward premium must be very large to have transition function values close to 1 and to validate the UIP condition. However, if forward premium is excessively low[9], the transition function will be close to zero. In this case, the UIP is not verified and the forward premium anomaly is validated. Our results confirm those of Wu and Zhang (1996), Bansal (1997), and Bansal and Dahlquist (2000) indicating that to reach the upper regime and to hold the UIP not only the dollar should be in premium, but the quoted premium must

Figure 1. Logistic transition function of MV-STR model estimates



also be enough large to insure reversion adjustment into the UIP. Baillie and Kiliç (2006) argue that the investors do not change their investment strategies only when the benefit issue of the new strategy exceeds transaction cost supported. This interpretation is coherent with argument of transaction cost and limit to speculation.

The rapid adjustment of the YEN and GBP to the UIP condition may be explained by carry and trade strategies adopted by investors over the period 1999-2007. Winters (2008) suggests that the carry trade, which is largely driven by cyclical interest rate differentials, contributes to the boost of the value of dollar vs. yen quickly over the period 2000-2007. This strategy may lead to an outflow of speculative investment from Japan. Carry trades typically involve borrowing in low-yielding currencies, such as the Japanese yen, and converting the funds into currencies with higher yields. The increased demand for foreign currency and the excess supply of yen combine to put downward pressure on the yen on a bilateral and real effective basis. Burnside *et al.* (2006) note that carry trade strategies yield high Sharpe ratios (relative to investments bearing a similar amount of risk) due to the low standard deviation of payoffs; however, the existence of transactions costs drastically reduces the returns to currency speculation. As a result, investors must hold on to carry trades for longer periods of time to make substantial returns.

V. Conclusion

This paper deals with the anomaly of premium on exchange market. Face to limits of linear models expressed widely by literature, we apply a non linear MV-LSTR model to better understand this anomaly. Our empirical results reject strongly the hypothesis of linearity against the non linear alternative. The model allows for two extreme regimes: A lower regime with forward premium that is less than a threshold level and consistent with the forward premium anomaly and an outer regime where UIP has a high probability of holding. We show that when Sharpe ratio is lower than a threshold level, deviation from UIP appears significant and persistent. Values of Sharpe ratio must be large enough to attract speculative capital departing from alternative trading strategies. We deduce that financial institutions will only take up a currency trading

Table 6. Estimation results of two-regime MV-LSTR- model

	USD/EUR	USD/GBP	USD/YEN
$\alpha_{s1} = -\alpha_{s2}$	– 0.0009	– 0.1528	0.0563
	(0.0010)	(0.0000)	(0.0003)
$\alpha_{f1} = \alpha_{f2}$	0.0001	0.0973	0.1849
	(0.0000)	(0.0000)	(0.0001)
$\beta_{s1} = 1 - \beta_{s2}$	– 0.8637	– 0.7313	0.0078
	(0.4338)	(1.8805)	(0.2632)
$\beta_{f1} = 1 - \beta_{f2}$	– 0.9274	– 0.7836	– 0.0559
	(2.8676)	(0.7346)	(0.5265)
γ_s	16.2576	11.2776	14.2950
	(2.3425)	(0.8098)	(0.0000)
γ_f	13.8062	10.7993	11.2730
	(1.6710)	(0.1305)	(0.7570)
c_s	0.0055	0.0175	0.03405
	(0.0003)	(0.0000)	(0.0006)
c_f	0.0051	0.03046	0.0305
	(0.0017)	(0.0000)	(0.0002)
LR	0.6186 4	0.6908	0.5494

strategy if the strategy yields a Sharpe ratio at least equal to an alternative investment strategy, as a buy-and-hold equity strategy.

The findings provide some support of limit to speculation hypothesis that we have used to motivate our methodology. We deduce that Sharpe ratios are economically very low to attract speculative capital particularly for GBP and YEN. However, when Sharpe ratio is high enough to attract speculators, the relationship between exchange and spot rates is rapidly reversed into the UIP. The major conclusion deduced is that the transition functions of forward exchange rate exert an important adjustment reversion effect to the UIP condition compared to the transition function of spot exchange rate. This adjustment is faster for the European market than those of GBP and YEN. For these two last currencies, the forward anomaly is very persistent relatively to EUR. In fact, for the GBP and YEN, the majority of transition function observations appear on the low regime. Our results confirm those of Wu and Zhang (1996), Bansal (1997), and Bansal and Dahlquist (2000) indicating that to reach the upper regime and to hold the UIP, is not enough that the dollar be in premium, but the quoted premium must also be enough large to insure reversion adjustment into the UIP. Baillie and Kiliç (2006) argue that investors do not change their investment strategies only when the benefit issue of the new strategy exceeds transaction cost supported. ■

1 For surveys see Lewis (1995), Engel (1996), or Sarno (2005). Some of the more recent contributions include Backus, Foresi and Telmer (2001), Beakert, Hodrick and Marshall (1997), Chaboud and Wright (2005), Chinn and Meredith (2005), Chinn and Frankel (2002), Fisher (2005), Flood and Rose (2002), Gourinchas and Tornell (2004), Mark and Wu (1998), Sarno, Valente and Leon (2006) and Verdelhan (2005).

2 Fama and Bliss (1987), Froot and Thaler (1990) and Bansal (1997).

3 Fama (1984), Hordrick (1987) and Engel (1996).

4 See Sarno and Taylor (2002) for a study of this evidence.

5 In the most common version of this strategy, an investor borrows a given amount in a low-interest-rate currency (the «funding» currency), converts the funds into a high-interest-rate currency (the «target» currency) and lends the resulting amount in the target currency at the higher interest rate.

6 The Sharpe ratio is defined by: $(E[R_s]-R_f)/\sigma_s$, where $E[R_s]$ is the expected return of the strategy. R_f is the return on a benchmark asset, such as the risk free rate of return and σ_s is the standard deviation of the excess return.

7 The model of Fama (1984) is expressed in equation (7).

8 To be related to literature researches we use the excess returns as transition variables in line with Bond, Harrisson, Hession and O'Brein (2006) and Sarno, Valente and Leom (2006).

9 In some cases negative.

References

- BAILLIE R.T. AND BOLLERSLEV T. (1994), "The long memory of the forward premium", *Journal of International Money and Finance*, vol 13: 565-571.
- BAILLIE R.T. AND KILIÇ R. (2006), "Do asymmetric and nonlinear adjustments explain the forward premium anomaly?", *Journal of International Money and Finance*, Elsevier, vol. 25 (1): 22-47.
- BANSAL R. (1997), "An exploration of the forward premium puzzle in currency markets", *Review of Financial Studies*, 10: 369-403.
- BANSAL R. AND DAHLQUIST M. (2000), "The forward premium puzzle: different tales from developed and emerging economics", *Journal of International Economics*, 51: 115-144.
- BAUM C.F., BARKOULAS J.T. AND CAGLAYAN M. (2001), "Nonlinear Adjustment to Purchasing Power Parity in the Post-Bretton Woods Era", *Journal of International Money and Finance*, 20: 379-399.
- BOND D., HARRISON M.J. AND O'BRIEN E.J. (2005), "Investigating Nonlinearity: A Note on the Estimation of Hamilton's Random Field Regression Model", *Studies in Nonlinear Dynamics and Econometrics*, vol. 9 (3): 1230-1230.
- BURNSIDE C., EICHENBAUM M., KLESHCHELSKI I. AND REBELO S. (2006), "The Returns to currency speculation", NBER Working Paper No. 12489.
- CORNELL B. (1977), "Spot rates, forward rates and exchange market efficiency", *Journal of Financial Economics*, 5: 577-585.
- DOUKAS J. AND RAHMAN A. (1987), "Unit Roots Tests: Evidence from the Foreign Futures Market", *The Journal of Financial and Quantitative Analysis*, 22 (1): 101-108.
- DUMAS B. (1992), "Dynamic equilibrium and the real exchange rate in a spatially separated world", *Review of Financial Studies*, 5: 153-180.
- DUMAS B. (1994), *Partial Equilibrium versus General Equilibrium Models of International Capital Market*, in van der Ploeg, F. (ed.), The Handbook of International Macroeconomics, Oxford: Blackwell.
- EITRHEIM A. AND TERÄSVIRTA T. (1996), "Testing the adequacy of Smooth Transition Autoregressive models", *Journal of Econometrics*, 74: 59-76.
- ENGEL C. (1996), "The forward discount anomaly and the risk premium: a survey of recent evidence", *Journal of Empirical Finance*, 3: 123-192.
- FAMA E.F. (1984), "Forward and spot exchange rates", *Journal of Monetary Economics*, 14: 319-338.
- FAMA E.F. AND BLISS R. (1987), "The Information in Long-Maturity Rates," *American Economic Review*, 77: 680-692.
- FRANSES P.H. AND VAN DIJK D.J. (2003), "Selecting a nonlinear time series model using weighted tests of equal forecast accuracy", *Econometric Institute Report 315*, Erasmus University Rotterdam.
- FROOT K.A. AND FRANKEL J.A. (1989), "Interpreting Tests of Forward Discount Bias Using Survey Data on Exchange Rate Expectations", *NBER Working Papers 1963*, National Bureau of Economic Research, Inc.
- FROOT K.A AND THALER R.H. (1990), "Foreign Exchange", *Journal of Economic Perspectives*, 4: 179-192.
- GUERRA R. (2002), "Forward Premium Unbiasedness Hypothesis: Old Puzzle, New Results", *Working Papers series No: 02.02*, University of Geneva.
- GRANGER C.W.J. AND LEE T-H. (1999), "The effect of aggregation on nonlinearity", *Econometric Reviews*, 18: 259-269.
- GRANGER C.W.J. AND TERÄSVIRTA T. (1993), *Modelling nonlinear economic relationships*, Oxford: Oxford University Press.
- GRANGER C.W.J. AND TERÄSVIRTA T. (1999), "A simple nonlinear time series model with misleading linear properties", *Economics Letters*, February, vol 62 (2): 161-165.
- GONZÁLEZ A., TERÄSVIRTA T. AND VAN DIJK D.J., (2005), "Panel Smooth Transition Regression Models", *Working Paper Series in Economics and Finance 604*, Stockholm School of Economics.
- HANSEN B.E. (1999), "The Grid Bootstrap and the Autoregressive Model," *Review of Economics and Statistics*, vol 81: 594-607.
- HODRICK R.J. (1987), *The Empirical Evidence on the Efficiency of Forward and Futures Foreign Exchange Markets*, London: Harwood.
- HOLLIFIELD B. AND UPPAL R. (1997), "An examination of uncovered interest rate parity in segmented international commodity markets", *Journal of Finance* 52: 2145-2170.
- JANSEN E.S. AND TERÄSVIRTA T. (1996), "Testing Parameter Constancy and Super Exogeneity in Econometric Equations," *Oxford Bulletin of Economics and Statistics*, November, vol. 58 (4): 735-63.
- KIM, C-J. AND NELSON C. (1998), "A Bayesian Approach to Testing for Markov Switching in Univariate and Dynamic Factor Models", *Discussion Papers in Economics*, n° 0059, University of Washington.
- KILIA L. AND TAYLOR M. (2003), "Why is it difficult to beat the random walk forecast of exchange rates?", *Journal of International Economics*, vol 60: 85-107.
- LEWIS K.K. (1995), *Puzzles in International Financial Markets*, in Grossman. G. and Rogoff. K. (eds.), The Handbook of International Economics, vol. 3. Amsterdam: New York and Oxford: Elsevier.
- LI Q., (1999), "Consistent model specification tests for time series econometric models", *Journal of econometrics*, Vol. 92 (1): 101-147.
- LUUKKONEN R., SAIKKONEN P. AND TERÄSVIRTA T. (1988 a), "Testing Linearity against Smooth Transition Autoregressive Models", *Biometrika*, Vol.75 (3): 491-499.
- LUUKKONEN R., SAIKKONEN P. AND TERÄSVIRTA T. (1988 b), "Testing Linearity in Univariate Time Series Models", *Scandinavian Journal of Statistic*, Vol. 15: 161-175.
- LUUKKONEN R., SAIKKONEN P. AND TERÄSVIRTA T. (1991), "Testing Linearity of Econmic Time Series against Cyclical Assymmetry", *Annales d'Economie et de Statistiques*, n°20/21: 125-142.
- MAYNARD A. AND PHILLIPS P.C. (2001), "Rethinking an Old Empirical Puzzle: Econometric Evidence on the Forward Discount Anomaly," *Journal of Applied Econometrics*, 16: 671-708.
- LYONS R.K. (2001), *The Microstructure Approach to Exchange Rates*, Cambridge and London: MIT Press.
- MARK N.C. AND MOH Y-K., (2002), "Continuous-time market dynamics, ARCH effects, and the forward premium anomaly", *working paper*, University of Notre Dame and Tulane University.

References (suite)

- Meese R.A. and Singleton K.J. (1982), "On Unit Roots and the Empirical Modelling of Exchange Rates", *Journal of Finance*, 37: 1029-1035.
- Michael P., Nobay R. and Peel D.A. (1997), "Transactions costs and Nonlinear adjustment in Real Exchange Rates: An Empircal Investigation", *Journal of Political Economy*, 105: 862-879.
- Moh Y-K. (2002), "Exchange rate dynamics in a continuous-time model of uncovered interest parity and the regulated jump-diffusion interest differential", *working paper 637*, Stockholm School of Economics.
- Obstfeld M. and Rogoff K. (2000), *The Six Puzzles in International Macroeconomics: Is There a Common Cause?*, in Bernanke B. and Rogoff K. (eds.), NBER Macroeconomics Annual, Cambridge: MIT Press, 339-390.
- Pesaran M.H. and Potter S.M. (1997), "A floor and ceiling model of US output," *Journal of Economic Dynamics and Control*, May, vol. 21 (4-5): 661-695.
- Peel D.A. and Taylor M.P. (2000), "Nonlinear Adjustment, Long-run Equilibrium and Exchange Rate Fundamentals", *Journal of International Money and Finance*, 19: 33-53.
- Peel D.A., Sarno L. and Taylor M.P. (2001), "Nonlinear Mean-Reversion in Exchange Rate Rates: Towards a Solution to the Purchasing Power Parity Puzzles", *International Economic Review*, vol 42: 1015-1042.
- Sakoulis G. and Zivot E. (2000), "Time-Variation and Structural Change in the Forward Discount: Implications for the Forward Rate Unbiasedness Hypothesis," *Econometric Society World Congress 2000, Contributed Papers 1583*, Econometric Society.
- Sarno L. and Taylor M.P. (2002), "Purchasing Power Parity and the Real Exchange Rate", *IMF Staff Papers, International Monetary Fund*, vol. 49 (1).
- Sarno L., Valente G. and Leon H.L. (2006), "Nonlinearity in Deviations from Uncovered Interest Parity: An Explanation of the Forward Bias Puzzle", *Review of Finance*, September, vol. 10 (3): 443-482.
- Sarrantis N. (1999), "Modeling Non-linearities in Real E€ective Exchange Rates", *Journal of International Money and Finance*, 18: 27-45.
- Sercu P. and Wu X. (2000), "Uncovered interest arbitrage and transaction costs: errors-in-variables versus hysteresis effects", *working paper*, City University of Hong Kong.
- Teräsvirta T. (1994), "Specification, estimation and evaluation of smooth transition autoregressive models". *Journal of the American Statistical Association*, 89: 208-218.
- Teräsvirta T. and Anderson H.M. (1992), "Characterizing nonlinearities in business cycles using smooth transition autoregressive models", *Journal of Applied Econometrics*, 7: 119-136.
- Verdelhan A. (2006), "A Habit-Based Explanation of the Exchange Rate Risk Premium", Mimeo, Boston University.
- Winters C. (2008), "The Carry Trade, Portfolio Diversification, and the Adjustment of the Japanese Yen", Discussion Paper, 2008-2.
- Wu Y. and Zhang H. (1996), "Asymmetry in forward exchange rate bias: a puzzling result", *Economics Letters*, 50 : 407-411.