

CARRY TRADE STRATEGIES WITH FACTOR AUGMENTED MACRO FUNDAMENTALS: A DYNAMIC MARKOV-SWITCHING FACTOR MODEL

Gokcen Ogruk, Texas Wesleyan University

ABSTRACT

This paper evaluates the performance of carry trade strategies with macro fundamentals in a Markov switching dynamic factor augmented regression framework and compares the performance statistics with the benchmark model of a random walk and momentum strategy. I make simulations with the Japanese Yen, Swiss Franc and US Dollar as funding currencies against six target currencies. Carry trade, a currency speculation strategy between the high-interest rate and low-interest rate currencies, generates high payoffs on average but has a possibility of crash risk. I argue that risk adjusted returns, mean returns and downside risk perform better when purchasing power parity model is used in a both regime switching and linear factor augmented regression framework for Franc trades and perform as good as benchmark model of momentum strategy for Dollar and Yen trades.

JEL: C22, E32, E37, E43, F31, F37, G15

KEYWORDS: Exchange Rate Models, Carry Trade, Forecasting, Markov-Switching Dynamic Factor

INTRODUCTION

Persistent interest differentials and low exchange rate volatility have underpinned significant crosscurrency positioning in recent years. One of the basic principles in finance is, if investors have zerocost investment, the expected return for that investment should be zero; otherwise there will be an arbitrage opportunity. The carry trade is an example of zero-cost investment, where the investors borrow from low-interest rate currencies and invest in high interest rate currencies in order to profit from the interest rate differentials. Carry trade is profitable contrary to economic and financial theories. Since traders invest in risk-free deposits, the only source of risk comes from exchange rate volatility. According to uncovered interest parity (UIP), the difference in interest rates between the two countries simply shows how much investors expect the high-interest-rate currency to depreciate against the low-interest-rate currency. If UIP holds, the carry trade strategy does not work, as higher yielding currencies will depreciate against lower yielding ones at a rate equal to the interest differential, equalizing expected returns for a given currency. The interest rate differential is expected to be fully offset by currency movements, neutralizing any profitable arbitrage opportunities from carry trading.

A large body of empirical literature documents that UIP fails at short and medium horizons but holds in the long term (Chinn and Quayyum 2012). Indeed, in the rest of the cases the relationship is precisely the opposite of that predicted by UIP: currencies with high interest rate tend to appreciate, not depreciate, while other currencies with low interest rates tend to depreciate, not appreciate. This failure of UIP is so well established that the phenomenon is called the "forward premium puzzle" and has been tested by an extensive literature that includes Frankel (1980), and Fama (1984). Carry trading is profitable for an unhedged currency strategy, when the interest rate differentials are high enough to compensate for exchange rate fluctuations. The profit from the carry trade is the sum of the interest rate differential and the forward premium between the two currencies. Carry trade involves risk due to potential exchange rate movements.

In fact, the high yield currency may depreciate against the low yield currency, increasing the amount initially borrowed in the funding currency in terms of target currency, and driving up the cost of borrowing. Since exchange rate movements are not offset by the interest rate differentials between the countries, carry traders tend to make huge profits.

It has been known that carry trades are profitable on average since the seminal paper by Meese and Rogoff (1983), who argue that the best predictor of next month's exchange rate is today's exchange rate. Thus, investors can make money on average by borrowing in currencies with low interest rates and investing in currencies with high interest rates. With the random walk model of exchange rates, the profit of carry trade comes from the yield spreads. Even though Meese and Rogoff (1983) show that economic models of exchange rates do not outperform the random walk forecast, many studies show the predictive ability of macro fundamentals for currency movements. Earlier research focused on the PPP and monetary approach in exchange rate forecasting, and recent studies have success in the prediction of exchange rate movements using the endogeneity of monetary policy with interest rate feedback rules such as Taylor rules (Molodtsova and Papell 2009). While the predictive power of Taylor rule and other macro fundamentals in exchange rate movements has been studied in the literature, these macro fundamentals and their predictive powers are not emphasized much as currency trading strategies. Jordà and Taylor (2012) show that the crash risk, or negative skewness, of the carry trade can be greatly reduced using fundamentals augmented carry trade strategies that take into account not only interest rate differentials, but also relative Purchasing Power Parity.

Li (2011) evaluates the profitability of the carry trades using Taylor rule fundamentals in exchange rate forecasting. He claims factor augmented Taylor rule fundamentals increase the profits of carry trade in a monthly frequency. This paper studies currency carry trade strategies based on macro fundamentals and regime switching risk premium factor in exchange rate forecasting. The starting point is to forecast exchange rates with macro fundamentals, focusing on Taylor rule and PPP models. These macro fundamental models are augmented with a regime switching risk premium factor. Risk premium factor is derived from excess returns of currency trading. The goal in building a non-linear risk premium factor is to capture both the nonlinearities in the currency market and the co-movements in the excess returns of the currency carry trading. Besides, the information extracted from the risk premium has the potential to increase the forecasting ability of macro fundamentals in exchange rate determination. Chauvet (1998) popularized the use of dynamic factors with Markov switching to characterize business cycles, however there is no paper in the literature that utilizes the nonlinear factor models to characterize the risk premium of currency trading. This empirical study uses time series data on the exchange rates of six major currencies against the Japanese Yen, Swiss Franc and five major currencies against the US Dollar.

For each of the six currencies, equally weighted portfolios are generated and the performance statistics of the returns are calculated. Random Walk (naive carry trade) and Momentum Models are chosen as the benchmark model. Random Walk Model is called as naive model since carry trades are executed in the naive sense, implying the investor's decision to execute carry trade depends on only interest rate differentials. Alternative strategies to the naive strategy are the models incorporating macro fundamentals and/or estimated non-linear and linear risk premium factors in exchange rate forecasting. Total of six trading strategies are simulated as an alternative to benchmark models. The empirical findings suggest that the mean returns, risk adjusted returns, downside risk, or negative skewness and maximum drawdown of the carry trades can be improved if the investors use PPP fundamentals that are augmented with a both nonlinear and linear factor. This result holds for both Franc and Dollar carry trades. In Yen trades, Momentum and PPP factor augmented models perform better than other models in the simulation. The remainder of this paper is organized as follows: The next section examines the related literature. In the following section, I describe the data, design of carry trade strategies, and methodology utilized in this study. Performance of carry trade strategies and discussion of the results are provided in the results section. The paper closes with some concluding comments and suggestions for future research.

LITERATURE REVIEW

The original academic literature claims that macroeconomic variables offer little help in exchange rate forecasting. Meese and Rogoff (1983) show that economic models of exchange rates do not outperform the random walk forecast model. Cheung et al. (2005) find that none of the macro fundamental models used in 1990s such as PPP fundamentals, sticky price monetary, productivity differential, uncovered interest rate parity and composite model of fundamentals can be successfully used by examining five developed countries' currency markets. Exchange rate determination can be consistent with macroeconomic fundamentals when monetary policy is taken to be endogenous with an interest rate feedback rule. Taylor rule models offer a different explanation to the exchange rate determination. Engel, Mark and West (2007) use uncovered interest rate parity directly to produce exchange rate forecast. They replace the interest rate differentials in the UIP by the interest rate differentials implied by Taylor rule, whereas Molodtsova and Papell (2009) used the variables that enter Taylor rule to evaluate the exchange rate forecast. Molodtsova and Papell (2009) find out that by assessing the out of sample performance of 12 currencies, the predictability of these models with Taylor rule fundamentals are stronger for 8 out of 12 currencies.

There are not many papers in the literature measuring the predictive ability of macro fundamentals in carry trading. Li (2011) evaluates exchange rate models with Taylor rule fundamentals from the perspective of the carry trader. The author claims that if the macro fundamental models of exchange rate including Taylor rule fundamentals do better than a random walk, this predictability power of exchange rate models may increase the profitability of carry trade strategies. He finds that carry trade models, using economic fundamentals in a factor augmented regression framework, have lower Sharpe Ratio and better downside risk. The results are robust to different time periods. Jorda and Taylor (2012) show that the crash risk of the carry trade can be reduced substantially by following macro fundamentals augmented carry trade strategies. They find that the nominal interest differential can help to predict exchange rate movements in the short run, but the forecast of exchange rates can be enhanced by including purchasing power parity (PPP). The deviation from PPP helps to forecast movements of the nominal exchange rate as the real exchange rate adjusts to its long run level. The authors show that there is a profitable trading strategy which includes a forecast that real exchange rate will return its long run level when its deviations from the mean are large.

Factor model forecasts of exchange rate are inspired by Engel et al. (2007). The authors mention that exchange rates themselves have an unobservable common component which may contain useful information for prediction. Engel et al. (2015) construct factors from a cross section of exchange rates and then use these estimated factors in the forecast equation of exchange rates. Using quarterly data from 1973 to 2007, factor augmented macro fundamentals model of exchange rate forecasts tends to improve on the forecasts of a random walk model in mean square error for their late sample, starting from 1999 and ending at 2007, although the factors themselves are not statistically significant. Using monthly data from 1999 to 2010, Greenaway, Mark, Sul and Wu (2012) perform a factor analysis on a panel of 23 nominal exchange rates where the factors are extracted from the exchange rate itself.

The authors identify the Euro/Dollar, the Swiss-Franc/Dollar and the Yen/Dollar exchange rates as the empirical counterparts to these common factors and find that the exchange rate factor augmented PPP Model has significant in sample and out of sample predictive power. Lustig et al. (2011) extract common factors from the excess currency returns associated with the carry trade. They claim that the global risk factor is the dominant factor. However, they do not use this factor for explaining the variation in exchange rates. Verdelhan (2015) uses these common risk factors that are derived from excess returns from carry trade to explain the variations in bilateral exchange rates. However, Verdelhan (2015) did not take into account these factors in exchange rate forecasting. This paper models excess return or the risk premium of currency trading by a Markov switching dynamic factor. This risk premium factor then augments both Taylor rule and PPP models of exchange rate forecasting in the forecasting equation of exchange rate. New carry trading strategies utilizing the information that is derived from the risk premium and the macro

fundamentals of exchange rate forecasting are examined in measuring the performance of carry trade in terms of profitability and risk.

DATA AND METHODOLOGY

The empirical analysis uses monthly data. The sample period includes the month end daily exchange rate data from FRED between January 1972 and December 2014 for pairs of the eight major currencies: The Australian Dollar (AUD), the Canadian Dollar (CAD), the Euro (EUR), the British Pound (GBP), the New Zealand Dollar (NZD), the Japanese Yen (JPY), the Swiss Franc (CHF), and the US Dollar (USD). Exchange rates of the target currency measured in the funding currency are computed as cross rates from their original dollar values. Of the eight currencies, six CHF and JPY cross rates are formed and five USD exchange rates are used. The data for macroeconomic fundamentals are constructed from the International Financial Statistics (IFS) and OECD Main Economic Indicators (MEI) databases. The seasonally adjusted Industrial Production Index is used as for countries' GDP, since GDP data is only available at quarterly frequency. The inflation rate is calculated from the Consumer Price Index, and is the annual rate measured as the 12-month difference of the CPI. The Money Market Rate is used for the monthly interest rate, which central banks set every period. German exchange rates and macro fundamentals are substituted for those of the Euro Zone before January, 1999.

The output gap calculations are based on potential output. The output gap is calculated as percentage deviations of actual output from a quadratic time trend, since there is no consensus about which definition of output is used by central banks. Quasi real time data in the output gap estimation is used. The quasi real time estimate is constructed in two steps. The first step begins with taking the final vintage of the output series with the observations up to, and including, t - 1 computing the quasi-real time estimate for period t. Then, in each period, the sample period is extended by one observation and OLS is used for de-trending. In the second step, the first available estimate of the output gap at each point in time that is constructed in the first step is collected. The final sequence of output gap series will be the quasi real time estimation of output gap data.

Carry Trade Strategies

Benchmark Models: The benchmark model is the naive carry trade strategy. Under the random walk theory, the carry trade, in its simplest form, depends solely on the interest rate differentials. This carry trade is called naive since it is unrelated to fundamentals other than interest rates. The second trading strategy is the momentum model of exchange rates. This strategy simply takes the current value of the change in exchange rate to be the best forecast of the change in exchange rate the next period. The naive and the momentum carry trade strategies can be described as:

Naive (Random Walk) (Model 1): The strategy focuses on only interest rate differentials.

$$\Delta \hat{e}_{t+1} = 0 \tag{1}$$

The variable e_t is the log of funding currency in units of target currency, so that an increase in e_t is an appreciation against funding currency.

Momentum (Model 2): The strategy takes the current value of exchange rate change as the best predictor of future.

$$\Delta e_{t+1} = \beta_0 + \beta_e \Delta e_t + \varepsilon_{t+1} \tag{2}$$

Macro Fundamentals Augmented Models: Purchasing Power Parity (PPP) holds in the long run, as many studies have confirmed. Under PPP, the exchange rate forecasting equation includes the price differences of the two countries. Following Jorda and Taylor (2012), PPP is incorporated into uncovered interest parity condition by expressing UIP in real, rather than nominal terms. Specifically, $r_t = i_t - \pi_{t+1}$ with $\pi_{t+1} = \Delta p_{t+1}$ and p_t is the log of national price level of the funding currency country. Jorda and Taylor (2012) form vector time series with changes in nominal exchange rates, differences in inflation rates and nominal interest rates between countries, where the levels of first two entries are I(1) variables which will be co-integrated if the PPP condition holds with co-integrating vector $q_t = e_t + p_t - p_t^*$. Jorda and Taylor (2012) use the weak PPP condition, $q_t = \bar{q} + \psi(p_t - p_t^*)$, as a co-integrating vector, where \bar{q} is the mean fundamental equilibrium exchange rate, and the Vector error correction model (VECM) as a currency trading strategy is expressed as:

VECM (Model 3):

$$\Delta e_{t+1} = \beta_0 + \beta_e \Delta e_t + \beta_\pi (\pi_t - \pi_t^*) + \beta_i (i_t - i_t^*) + \beta_q (q_t - \bar{q} - \psi(p_t - p_t^*) + \varepsilon_{t+1}$$
(3)

The Taylor rule relates changes in the interest rate to inflation and the output gap. Many researchers and policy makers assess the validity of the Taylor rule in both developed and developing countries (Clarida et al. (1998), Osterholm (2005), and Bhattaraii (2008)).

Following Taylor (1993), central banks follow the below reaction function for the monetary policy rule:

$$i_t = \pi_t + \theta(\pi_t - \tilde{\pi}) + \delta y_t + \tilde{r}$$
(4)

where i_t is the federal funds rate, π_t is the inflation rate, $\tilde{\pi}$ is the target level of inflation, y_t is the output gap and \tilde{r} is the equilibrium level of real interest rate.

The parameters $\tilde{\pi}$ and \tilde{r} are constant and can be sum up to form single term = $\tilde{r} - \theta \tilde{\pi}$. Therefore, the equation (3.5) can be written as: $i_t = \mu + \varphi \pi_t + \delta y_t$ (5)

where $\varphi = 1 + \theta$. Clarida, Gali and Gertler (1998) assume that the actual observable interest rate gradually adjust to its target level. Therefore, the Taylor's original formulation with interest rate smoothing becomes as follows:

$$i_{t} = (1 - \rho)(\mu + \varphi \pi_{t} + \delta y_{t}) + \rho i_{t-1}$$
(6)

Following Molodtsova and Papell (2009), Taylor rule fundamentals are used for exchange rate determination. The interest rate differentials between the target currency and the funding currency is replaced by the Taylor rule fundamentals. Although Molodtsova and Papell (2009) consider different specifications for the Taylor rule fundamentals, the formulation with interest rate smoothing, where the interest rate is characterized by the inflation gap, the output gap, the equilibrium interest rate, and the lagged interest rate is followed. It is assumed that both central banks follow a similar rule and they respond identically to the inflation and the output gaps. Therefore, the Taylor rule coefficients will be identical for both countries. It is also assumed, the two central banks have different inflation targets and equilibrium interest rates. With these assumptions, the Taylor rule as a currency trade strategy is:

Taylor Rule Fundamentals (Model 4):

$$\Delta e_{t+1} = \beta_0 + \beta_1 (\pi_t - \pi_t^*) + \beta_2 (y_t - y_t^*) + \beta_3 (i_{t-1} - i_{t-1}^*) + \varepsilon_{t+1}$$
(7)

Star indicates the values for the target currency country. π_t and y_t are the inflation and output gaps respectively. Alternative models with Taylor rule fundamentals are also considered. For instance, Taylor rule fundamentals in a non-switching factor augmented regression framework and Taylor Rule fundamentals combined with Momentum strategy are used as forecasting equation for the exchange rates.

Factor Augmented Macro Fundamentals Models: VECM and Taylor Rule Model in a non-switching and switching factor augmented regression framework are used as forecasting equation for the exchange rates. *VECM with Non-Switching Factor (Model 5):*

$$\Delta e_{t+1} = \beta_0 + \beta_C \widehat{C}_t + \beta_e \Delta e_t + \beta_\pi (\pi_t - \pi_t^*) + \beta_i (i_t - i_t^*) + \beta_q (q_t - \bar{q} - \psi(p_t - p_t^*) + \varepsilon_{t+1}$$
(8)

Taylor Rule Fundamentals with Non-Switching Factor (Model 6):

$$\Delta e_{t+1} = \beta_0 + \beta_C \widehat{C}_t + \beta_\pi (\pi_t - \pi_t^*) + \beta_y (y_t - y_t^*) + \beta_i (i_{t-1} - i_{t-1}^*) + \varepsilon_{t+1}$$
(9)

 C_t is the non-switching dynamic factor that is estimated by maximum likelihood estimation.

VECM with Markov-Switching (MS) Factor (Model 7):

$$\Delta e_{t+1} = \beta_0 + \beta_F F + \beta_e \Delta e_t + \beta_\pi (\pi_t - \pi_t^*) + \beta_i (i_t - i_t^*) + \beta_q (q_t - \bar{q} - \psi(p_t - p_t^*) + \varepsilon_{t+1}$$
(10)

Taylor Rule Fundamentals with Markov-Switching (MS) Factor (Model 8):

$$\Delta e_{t+1} = \beta_0 + \beta_F \hat{F}_t + \beta_\pi (\pi_t - \pi_t^*) + \beta_y (y_t - y_t^*) + \beta_i (i_{t-1} - i_{t-1}^*) + \varepsilon_{t+1}$$
(11)

In equation 10 and 11, the Markov switching factor, \hat{F}_t , is estimated by approximate MLE using both the Kalman Filter and the Hamilton Filter together.

Modelling and Estimating the Factor

A vector of excess returns is modeled as a combination of two stochastic autoregressive processes; a single unobserved component, which is the common factor for the observable variable (risk premium), and an idiosyncratic component. The empirical analysis is done by using the log of first difference of the spot exchange rates, and the interest rate differentials of target and funding countries. The sum of these two macroeconomic data is defined as the observable variable displaying co-movements with the aggregate economic conditions. The model is:

$$y_{i,t} = i_{i,t}^* - i_{i,t} + \Delta e_{i,t+1} \qquad i = 1, \dots, n$$
(12)

$$y_{i,t} = \lambda_i F_t + \varepsilon_{i,t} \qquad \qquad i = 1, \dots, n \tag{13}$$

$$F_t = \mu_{st} + \nu_t \qquad \qquad S_t = 0,1 \tag{14}$$

$$\varepsilon_{i,t} = \gamma_i \varepsilon_{i,t-1} + \epsilon_{i,t} \qquad \qquad i = 1, \dots, n \tag{15}$$

The assumptions of the model are:

$$v_t \sim i. i. d. \quad N(0,1)$$

 $\epsilon_{i,t} \sim i. i. d. \quad N(0, \Sigma)$

$$p_{ij} = Prob[D_{t=j}|D_{t-1=i}], \ \sum_{j=1}^{M} p_{ij} = 1 \qquad \forall i \in M \ states$$

 $y_{i,t}$ is the excess return, the parameters λ_i are the factor loadings, which measure the sensitivity of the *i*th series to the contractions and expansions in the economy, and F_t is the common factor. The idiosyncratic term $\varepsilon_{i,t}$ is serially uncorrelated at all leads and lags, $\varepsilon_{i,t}$ is the measurement error. A nonlinear structure is introduced in the unobserved component in the form of a first order two state Markov switching process. There are two states in the economy: a contraction, $(S_t = 0)$ or an expansion, $(S_t = 1)$. Excess returns of the currency trading are modeled such that the only source of co-movements comes from the unobservable dynamic factor. The basic idea of the model is to allow the mean of unobservable common factor to take two distinct values during the times of expansions and contractions. The regime at any given time is presumed to be the outcome of a Markov chain whose realizations are unobserved. The two regimes at any given time are characterized by the transition probabilities of the Markov process. For example, $Prob[S_t = 1|S_{t-1} = 1] = p$ is the probability of an expansion, and $Prob[S_t = 0|S_{t-1} = 0] = q$ is the probability of contraction. The state space representation for the switching dynamic factor (12) - (15) with the AR (1) process for the disturbance term is explained in Appendix A. The measurement equation and the transition equation in vector notation can be written:

$$Y_t = HB_t \tag{16}$$

$$B_t = \alpha_{st} + ZB_{t-1} + u_t \tag{17}$$

With the dynamic factor model of Stock and Watson (1989) and the regime switching model of Hamilton (1989), excess returns of the observed currency pairs from the carry trade depend on the current and lagged values of an unobserved common factor. This common factor captures the co-movements between the risk premium of each currency trading and is dependent on whether the economy is in the recession state or in the boom state. The dynamic factor model with regime switching is estimated by maximizing its likelihood function. Kim's algorithm (1999) is used to estimate the model. Kim extended Hamilton's Markov switching Model to a linear dynamic state space representation. He allows the regime switching in both the transition and measurement equation. His algorithm combines nonlinear discrete Kalman Filter with Hamilton's nonlinear filter, which allows both the estimation of an unobserved state vector and the transition probabilities. The procedure to estimate the model starts with recursively calculating one step-ahead predictions and updating equations of the dynamic factor, given the starting values and the probabilities of the Markov States. The probability terms are calculated using Hamilton's Filter. This nonlinear filter computes for the two state Markov switching process four forecasts at each date and the number of cases is multiplied by two at each iteration. Since this approach makes the Kalman Filter computationally infeasible, Kim (1999) proposes an approximation consisting of taking weighted averages of updating equations by the probabilities of Markov States.

As a byproduct of the filter, the conditional density of the observable variables that is calculated will then be used to estimate the unknown parameters of the model. These parameter estimates will be recursively substituted into Kalman Filter until the estimates of parameters converge. The maximum likelihood estimators and the sample data are then used in the final application of the filter to draw inferences about the dynamic factor and the probabilities. The estimation procedure is discussed in details in the Appendix B. Several different specifications of the model are estimated, including an AR (1) and an AR (2) factor with an AR (1) and an AR (2) idiosyncratic terms for the observables. Combinations of these models are also tested. However, highly parameterized models with higher dynamic orders have coefficients that are not significant at the 5 percent significance level. The likelihood ratio test is used to choose among the alternative specifications of the model. For the adequacy of the model selection, the disturbances in the observable variables are analyzed. The correctly specified model has estimated disturbances that are not serially uncorrelated implying the sample autocorrelations should be zero and the disturbances should be white noise. The diagnostic tests for the data state that the specifications that are selected for the model are adequate. Identifying the number of common factors that explain common variations in a set of observable variables is one of the major tasks of factor analysis. The most widely used is the Scree test. The Scree test is a visual test based on the behaviors of the eigenvalues of the second moment matrix of the observable variables. In this paper, the number of factors is verified by checking the eigenvalues of the correlation matrix containing the total variance of the observables and for visual inspection the Scree test is used. The magnitude of the eigenvalues, which contains information about how much of the correlations among the observable variables, is explained by a particular factor, shows there is a single factor in the data.

Designing Carry Trade Strategies

The currency carry trade is designed to exploit the failure of UIP and consists of borrowing in a low interest rate currency and lending in a high interest rate currency.

$$X_{t} = \begin{cases} > 0 & if \ I_{t} < I_{t}^{*} \\ < 0 & if \ I_{t} > I_{t}^{*} \end{cases}$$
(18)

Ignoring the transaction costs, the payoff to the carry trade in domestic currency is:

$$X_t \left[E_t (1 + I_t^*) \frac{1}{E_{t+1}} - (1 + I_t) \right]$$
(19)

The variable E_t denotes the spot exchange rate, expressed as domestic currency per foreign currency unit, and X_t is the amount of domestic currency borrowed. The variables, I_t and I_t^* , represent the domestic and foreign interest rate, respectively. Thus, the return of an investment in the foreign currency financed by the domestic currency consists of both interest rate differentials between the two countries and the changes in the exchange rate. The logarithm of nominal exchange rate (units of foreign currency per domestic currency) is denoted by e_t , interest rate by i_t and foreign interest rate by i_t^* . The return of an investment in the foreign currency financed by borrowing in the domestic currency is denoted by:

$$x_{t+1} = i_t^* - i_t + \Delta e_{t+1} \tag{20}$$

 $\Delta e_{t+1} = e_{t+1} - e_t$ is the appreciation of the foreign currency (e.g., Δe is the change in yen exchange rate). Equation (20) is the excess return that is gained from carry trading when UIP is violated. If UIP holds, this excess return will not be forecasted and $E_t(x_{t+1}) = 0$. Therefore, x can be considered as an abnormal return to the carry trade strategy where foreign currency is the investment currency and Japanese Yen, Swiss Franc and US Dollars are the funding currency. In this paper, a carry trade is defined as a binary trading strategy that is based on expected returns. There is a trade between the funding currency country and the target currency country if the interest rate differential between the target country and funding country is positive and the expected return is positive as predicted by the model. The execution of carry trade is denoted by $\hat{b}_{i,t} = 1$:

$$\hat{b}_{i,t} = \begin{cases} 1 & if \ i_{i,t}^* - i_{i,t} + E_t (\Delta e_{i,t+1}) > 0\\ 0 & otherwise \end{cases}$$
(21)

Consider the case where e_t follows a random walk:

$$E_t(\Delta e_{t+1}) = 0 \tag{22}$$

Under the random walk model, the carry trade, in its simplest form, depends solely on the interest rate differentials. This carry trade is called "naive" since it is unrelated to fundamentals other than the interest rate. For one unit of borrowed investment currency, the returns for the different specifications of a carry trade are computed with the realized exchange rates:

$$x_{i,t} = \begin{cases} i_{i,t}^* - i_{i,t} + \Delta e_{i,t+1} & \text{if } \hat{b}_{i,t} = 1\\ 0 & \text{if } \hat{b}_{i,t} = 0 \end{cases}$$
(23)

 x_t is the return from binary trading strategy at period t.

Forecasting and Statistical Evaluation of Carry Trades

The out-of-sample performance starts in January 1999, when the Euro became official. First, the non-linear unobservable factor and factor loadings are estimated. After obtaining the sequence of factors and factor loadings, the coefficients of the models, which include the factor as an explanatory variable, using the OLS method to forecast exchange rates for that month are estimated. As depicted in (24), the data from 1979:12 through 1998:12 to estimate factors and factor loadings and construct $\hat{F}_{i,t} = \hat{\lambda}_i \hat{f}_t$ for all cross currencies.



The forecasting equation is combining both the macro fundamentals and the estimated factors in a single equation,

$$\hat{e}_{i,t+1} - \hat{e}_{i,t} = E_t (\beta_i + \beta_F \hat{F}_t + z_{i,t}) \qquad t = 1999:1, \dots, 2014:12$$
(25)

 $z_{i,t}$ is the different specification of the macro fundamentals. The out of sample forecast is done by estimating each equation by OLS in a rolling regression framework. Each model is initially estimated using the first 229 data points to generate the one-period-ahead forecast. Then the first data point is dropped, an additional data point is added at the end of sample and the model is re-estimated. A one month ahead forecast is generated at each step. The out of sample forecast is then used to determine the value of b_t , the binary decision making function of the carry trade at time t. With JPY and CHF as the funding currencies, this process is performed for each of the six nations, whereas when using USD, it is performed for each of 5 nations. 192 months of trade decisions are computed from 1999:1 to 2014:12. The out of sample period includes the 2008-2009 financial crises, in which several crash episodes took place, providing a realistic assessment of the crash episode returns at that time.

Performance statistics of the carry trade returns include the *Mean Return*, *Standard Deviation*, *Sharpe Ratio*, *Return Skewness*, *Return Kurtosis* and *Maximum Drawdown* of returns from the period 1999:1 to 2014:12. The performance statistics are based on an equally weighted portfolio of 6 currencies against the JPY and the CHF, 5 currencies against the USD. One of the popular methods of summarizing the properties of a return of an asset or an investment is *Sharpe Ratio*. It is calculated as a ratio of returns normalized by the standard error. The Sharpe Ratio is good for evaluating how well the return of an asset compensates the investor for the risk taken. A portfolio or a return may have higher mean returns than its peers, however, it is better when it does not have additional risk. Therefore, the greater the Sharpe Ratio, the better its risk adjusted performance is.

In this paper, *Return Skewness* and *Kurtosis* are used as measures of the risk of large amount of losses. Skewness is a measure of degree of asymmetry of a distribution while Kurtosis measures the height and sharpness of the peak. A negative Skewness implies that the left hand side tail of the probability density function is longer than the right hand side tail, and the mass of values lies to the left of the mean of the distribution. A large positive number for the Kurtosis shows a higher and sharper peak. The exchange rate movements are not symmetric when they go up and down. This asymmetry of exchange rate movement is associated with a crash risk. Brunnermeier (2008) claim that the movements of exchange rates between high yield and low yield currencies are negatively skewed and, therefore, are subject to crash risk. Consequently, in this paper, we used Skewness to show the risk of large losses by carry traders in case of market crashes and Kurtosis to show that whether these changes are abrupt or not. Large negative Skewness implies that there is higher probability of these large losses, while positive big Kurtosis shows that these changes are fast. The *Maximum Drawdown* is also an important performance statistic for the risk of a portfolio. It measures the largest single drop from the peak to bottom before a new peak is reached. Therefore, the Maximum Drawdown measures the largest possible loss since the beginning of the portfolio. Large Maximum Drawdowns indicate higher risk.

RESULTS AND DISCUSSION

Summary Statistics

Some basic statistics for the sample from 1972 to 2014 are presented in Table 1. The basic statistics indicate that since the standard deviations are high, all variables are volatile. Target currencies on average have higher interest rates than funding currencies (note that the interest rate differential is defined as the difference between the target currency country and the funding currency country) which indicates that there is a profit opportunity in borrowing from the funding currency and investing into the target currency. However, due to depreciation of the funding currency over the sample period, which does not fully offset the interest rate differential in most cases, the gain (the sum of interest rate differentials and change in exchange rate in Table 1) from carry trade is positive, but less than interest rate differentials. For instance, the Australian Dollar, a typical investing currency, has a sizeable interest rate differential, which is not offset by the appreciation of funding currency.

	AUSTRALIA	CANADA	EUROPEAN	UNITED	NEW	UNITED			
			UNION	KINGDOM	ZEALAND	STATES			
Panel A: Funding Currency Is Japanese Yen									
Δe	-0.003	-0.002	0.001	-0.003	-0.003	-0.002			
	(0.033)	(0.030)	(0.038)	(0.029)	(0.032)	(0.027)			
$i^* - i$	0.007	0.005	0.004	0.005	0.008	0.005			
	(0.003)	(0.004)	(0.002)	(0.004)	(0.004)	(0.003)			
Panel B: Fund	ing Currency Is Sv	viss Franc							
Δe	-0.003	-0.002	0.001	-0.003	-0.003	-0.002			
	(0.033)	(0.030)	(0.038)	(0.029)	(0.032)	(0.027)			
i* – i	0.007	0.005	0.004	0.005	0.008	0.005			
	(0.003)	(0.004)	(0.002)	(0.004)	(0.004)	(0.003)			
Panel C: Funding Currency Is Us Dollar									
Δe	-0.003	-0.002	0.001	-0.003	-0.003	-0.002			
	(0.033)	(0.030)	(0.038)	(0.029)	(0.032)	(0.027)			
i* – i	0.007	0.005	0.004	0.005	0.008	0.005			
	(0.003)	(0.004)	(0.002)	(0.004)	(0.004)	(0.003)			

Table 1: Summary Statistics

This table shows summary statistics of depreciation of funding currency, interest differentials between target and funding currency country. The numbers in the parenthesis are the standard deviations. An asterisk indicates values for the target currency. Δe is the percentage change in the exchange rate (An increase in the exchange rate implies depreciation of the funding currency). The interest rate is money market rate. The interest rate data of New Zealand is available from 1973:12 to 2014:12, Canada 1975:01 to 2014: 12.

Table 1 shows that there is a positive correlation between average interest rate differentials and average excess returns, which points to the violation of UIP in the data. The currencies with the average positive interest rate differentials against the funding currencies have positive average excess returns and the currencies with average negative interest differentials have negative average excess returns. For instance, an investor making a carry trade in investing in Australian Dollar financed by borrowing Japanese Yen during the sample period would have earned the sum of the average interest rate differential and the change in exchange rate, which is 4 percent annually.

Empirical Results of Markov Switching Dynamic Factor Model

The monthly exchange rate and interest rate data are used to calculate risk premium. The inferred probabilities, parameter estimates and factor loadings are estimated from the switching dynamic factor. The estimates obtained through numerical maximization of the conditional log likelihood function are presented in Table 2. There is significantly positive growth in state 1 and significantly negative growth in state 2 for all currency returns. The asymmetries in the phases of the states are well defined by the switching dynamic factor. The probability of staying in expansion, p, is higher than the probability of staying in contraction, q. The estimated transition probabilities for the expansion state are highly significant and persistent for the Japanese Yen and the US Dollar. For Franc trades, the expansion state is not as persistent as the other currency trades, p = 0.84.

Table 2: Approximate Maximum Likelihood Estimates of the Model

		JAPAN	SWITZERLAND	USA
LIKELIHOOD VALUE		-716.53	-869.47	-1068.71
	p (State 1=Expand)	0.96***	0.84***	0.95***
Parameter Estimates of	• • • •	(0.02)	(0.04)	(0.03)
Markov-Switching	q (State	0.43***	0.64***	0.79***
Dynamic Factor	2=Contract)	(0.12) (0.14)		(0.12)
	μ_0 (State 1 Mean)	-2.64***	-1.14**	-1.16**
		(0.40)	(0.30)	(0.37)
	μ_1 (State 2 Mean)	2.82***	1.66***	1.46***
	,	(0.37)	(0.34)	(0.34)
	$\lambda_{Australia}$	0.66***	0.62***	0.71***
	nustruttu	(0.04)	(0.04)	(0.05)
	λ_{canada}	0.78***	0.76***	0.52***
	oundud	(0.04)	(0.05)	(0.05)
Factor Loadings	λ _{United Kinadom}	0.34***	0.18***	0.35***
-	onnou ninguom	(0.04)	(0.04)	(0.05)
	$\lambda_{European IInion}$	0.58***	0.48***	0.41***
	Baropean enten	(0.04)	(0.04)	(0.05)
	JNow Zogland	0.63***	0.57***	0.70***
	New Zeutunu	(0.04)	(0.04)	(0.05)
	$\lambda_{United States}$	0.72***	0.70***	-
	onica states	(0.04)	(0.05)	

This table shows inferred probabilities, parameter estimates and factor loadings that are estimated from the switching dynamic factor. The estimates obtained through numerical maximization of the conditional log likelihood function. The sample period is 1979:12 to 2014:12. Japanese Yen is the funding currency in the first column. The standard errors are given in the parenthesis.

With respect to the factor loadings of the Yen carry trade; the Canadian and the US Dollar excess returns have the highest coefficients, supporting the observation that they are the most sensitive returns to expansions and contractions. Overall, all factor loadings are highly significant, implying the risk premium for all currencies is highly sensitive to the regime switches in the economy. The same results are true for the Franc and the US Dollar trades. The US and the Canadian Dollar have the highest significant factor loadings for the Franc carry trade returns. The New Zealand Dollar has the highest parameter estimates for

the US Dollar trade returns, and all of the excess returns are significantly affected by the state of the economy. The Markov Switching Dynamic Factor Model for the risk premium is very useful in several aspects. First, there is a significant unobservable component that is derived from the excess returns of carry trading and this unobservable component's conditional mean changes depending on the contractions and expansions of the economy for all currency pairs. This result implies that the currency risk premium is sensitive to regime switches in the economy. Besides, the expansion state is persistent for both Yen and Dollar returns, indicating that if the economy is in a state of expansion, the duration of that expansion is long.

Performance Statistics of the Carry Trade Returns

The carry trades are constructed with the target currency countries that have higher interest rate differentials on average than the funding currency country. There are six individual carry trades with the Yen and the Franc and five individual trades with the Dollar. In practice an investor can apply the carry trade strategy either to individual currencies or to portfolios of currencies. Burnside (2011) claims that the risk in carry trade strategies is reduced by diversifying the carry trade across different currencies. In this section, the perspective of an individual currency trader is taken into account, and whether this trader gains more by diversifying a carry trade across different currencies or not is examined. Equally weighted carry trade strategies are constructed where the Yen, Franc and Dollar positions are given equal weight at each point in time to all the currencies. They are based on one period ahead forecast of exchange rates with rolling window samples beginning in January 1999 to December 2014. The out of sample forecasts include the financial crisis of 2008-2009 where crash episodes took place, so that forecasting analysis provides a realistic assessment of the type of returns that could have made at that time.

	Naive (Random Walk)	Momentum	VECM	Taylor Rule	VECM Factor Aug.	Taylor Rule Factor Aug.	VECM MS- Factor Aug.	Taylor Rule MS- Factor Aug.
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Panel A: Fu	Inding Currei	icy Is Japanese	Yen					
Mean	0.04	0.05	0.02	0.04	0.05	0.03	0.05	0.03
SE	0.09	0.06	0.06	0.07	0.06	0.07	0.06	0.07
SR	0.41	1.00	0.38	0.53	0.91	0.51	0.91	0.41
Skew.	-0.15	0.68	0.40	-0.61	0.65	-0.65	0.65	-0.48
Kurtosis	5.29	4.14	3.28	4.32	3.43	4.52	3.48	4.49
Max D.	0.34	0.07	0.19	0.24	0.14	0.23	0.13	0.23
Panel B: Fu	unding Currer	ncy Is Swiss Fran	nc					
Mean	0.02	0.02	0.01	0.02	0.03	0.02	0.03	0.01
SE	0.07	0.04	0.05	0.05	0.05	0.05	0.05	0.04
SR	0.26	0.52	0.29	0.48	0.59	0.49	0.56	0.33
Skew.	-1.44	-0.60	2.74	3.26	2.53	2.62	2.72	-0.41
Kurtosis	11.3	1.93	24.7	29.4	20.9	23.5	23.4	1.26
Max D.	0.26	0.13	0.12	0.10	0.10	0.11	0.12	0.11
Panel C: Fu	unding Currei	ncy Is Us Dollar						
Mean	0.03	0.05	0.04	0.03	0.04	0.04	0.05	0.05
SE	0.07	0.06	0.06	0.06	0.06	0.05	0.06	0.07
SR	0.43	0.82	0.60	0.48	0.77	0.78	0.83	0.72
Skew.	-0.97	1.74	1.86	-0.66	0.29	0.23	1.89	0.08
Kurtosis	5.22	11.7	12.4	3.36	1.03	1.59	11.6	2.01
Max D	0.28	0.11	0.12	0.23	0.11	0.10	0.10	0.12

Table 3:	Performance	of Carry	v Trade Returns
1 4010 5.	1 vi i vi i unune e	or curry	y Indde Recuillo

This table reports performance statistics of carry trade returns for all currencies sample period is from 1999:01 to 2014:12. The total number of observations is 192. The Sharpe Ratio is the mean returns divided by standard deviations. All returns are annualized. Equally weighted portfolio is calculated as giving equal weight to each currency trade in time (Funding currencies are: The Australian Dollar, Canadian Dollar, UK Pound, Norwegian Krone, New Zealand Dollar, US Dollar for Panel A and B). Mean is mean return, SE is standard errors, SR is Sharpe Ratio, Skew. is skewness, Max D. is maximum drawdown.

The results are based on an equally weighted portfolio of the six currencies against the Japanese Yen and the Swiss Franc and five currencies against the US Dollar. Performance statistics include the annualized return, Sharpe Ratio, return skewness, kurtosis and maximum drawdown. All carry trading strategies have positive mean returns ranging from 1 % to 6 % annually. The mean return is low in Franc trades compare to Yen and Dollar trades. Models with both factor augmented and dynamic factor augmented PPP (VECM) fundamentals perform better than benchmark models of naive and momentum for Franc trades, and perform as good as benchmark model of momentum for Dollar trades. Factor augmented VECM performs as good as momentum model and better than most of other models, but much better than the naive trading strategy for Yen trades. The Sharpe ratios of carry trade strategies are usually low, since, although the mean excess returns for carry trade strategies are moderate, the volatility for those returns is high. It is clear that carry trade strategies with benchmark model of momentum strategy has larger Sharpe ratio than other models in the simulation, implying carry trades with those models are more profitable on average than the other models in Yen trades. MS-factor augmented VECM model slightly better than momentum strategy in terms of Sharpe ratio for Dollar trades.

While the Sharpe ratio suggests whether the carry trade strategies have low or high risk return profiles, it does not account for either the crash risk or downside risk. The maximum drawdown measures the largest possible loss, whereas skewness measures the possibility of large losses or gains during market crashes. From Table 3, for the naive model, all currency carry trade returns have negative skewness, high kurtosis and high maximum drawdown, which means that carry trade returns with all currencies have a crash risk and large losses in carry trades based on solely on interest rate differentials will be fast. The results for all currency trade show that the negative skewness is improved when traders use both factor augmented and MS- Factor augmented VECM models in exchange rate forecasting. Table 3 (Panel A) reports that naive Yen carry trade has a skewness of -0.15. Linear and non-linear factor augmented VECM models improve the skewness of the returns. For Dollar carry trades, Table 3 Panel C, the return skewness in the naive model becomes a positive number with MS-factor augmented VECM model (Model 6) as with all other factor augmented macro fundamental models. The payoffs of random walk model in Swiss Franc trades have a significant probability of large losses in a case of market crash with a negative skewness of -1.44. Carry trade returns are positively skewed in all factor augmented macro fundamentals models except Taylor Rule model in Franc trades.

The naive model for all currency carry trades have a maximum drawdown ranging from 26 % to 34 %. The reason for such a large downside risk is simple: There are several episodes of target currency collapses during the simulation period. Every crash in a target currency against the funding currency significantly increases the downside risk in the carry trade. Factor augmented macro fundamental models impressively reduce the downside risk. In Franc and Dollar trades, maximum drawdown is reduced to 10 % (Model 5 and Model 7 respectively). In Yen trades similar improvement in the downside risk can be seen with factor augmented VECM models (Model 5 and Model 7); maximum drawdown decreased to 13 %.

CONCLUSION

This paper provides evidence of enhancing carry trade returns when factor augmented macro fundamentals are used as a trading strategy with an equally-weighted portfolio of individual currency trades. The factor is derived from the excess returns of currency trading and subject to regimes switching. Alternative carry trading strategies with factor augmented macro-fundamentals document that these alternative macro-fundamental trading strategies are better than a naive strategy and they perform as good as momentum strategy. Moreover, factor augmented VECM model performs the best than the benchmark model of the random walk and momentum strategy in terms of mean returns, downside risk and risk adjusted returns for Franc trades. The crash risk of carry trades that is inherit in benchmark model of random walk is reduced,

and the negative skewness is improved to a positive level in Dollar carry trades with factor augmented macro fundamental models. However, this paper does not find evidence of superiority of nonlinear factor augmented models over linear factor augmented models. Regime switching factor augmented macro fundamental models perform as good as factor augmented macro fundamental models in most cases. Besides, factor augmented macro fundamentals do not beat the benchmark model of Momentum strategy in most cases. Momentum strategy performs the best in Yen trades, performs as good as factor augmented macro fundamentals in Dollar trades.

Overall, my results are consistent with the view that returns to carry trade have high mean returns and low Sharpe Ratios with a possibility of crash risk. This crash risk is reduced when models with factor augmented macro fundamentals are used as trading strategies throughout the sample period. As well, there is profitable carry trading when PPP (VECM) fundamentals are used in both linear and nonlinear factor augmented framework for Franc trades. This could be the outcome of the predictive power of macro fundamentals in exchange rate movements and the inclusion of an estimated factor derived from risk premium into the forecasting equation of exchange rates. Finally, the result that trading strategies with factor augmented macro fundamentals have better performance in mean and risk adjusted returns would be helpful to the practitioner, since these trading strategies are more profitable than naive carry trade strategy.

This study is limited in several ways. First, emerging markets carry trades are not included in this study. The currencies of the lower-interest countries have been invested in emerging markets in order to benefit high interest differentials between funding currency and emerging country currency, especially after financial crisis of 2008-2009 when the interest rates hit the zero lower bound in the US. A second limitation is the exclusion of transaction cost in the analysis. Some studies use a 10 basis point round-trip transaction cost for trading in currency markets. However, assuming a constant rate of 10 basis point round-trip transaction cost for trading may not be accurate for all currencies. In a future study, I plan to address these issues by measuring transaction costs of currency trading with bid ask spreads, and examining performance of carry trade strategies in emerging market economies.

APPENDIX

Appendix A: State Space Representation of Empirical Model

Measurement Equation:

Y_t		E	ł				B_t	
Y_{1t} Y_{2t} Y_{3t} Y_{4t} Y_{5t} Y_{6t}	$=\begin{matrix} \mathcal{\lambda}_1\\ \mathcal{\lambda}_2\\ \mathcal{\lambda}_3\\ \mathcal{\lambda}_4\\ \mathcal{\lambda}_5\\ \mathcal{\lambda}_6 \end{matrix}$	1 0 0 0 0 0	0 1 0 0 0 0	0 0 1 0 0 0	0 0 1 0	0 0 0 1 0	$\begin{array}{c c} 0 & F_t \\ 0 & \varepsilon_{1t} \\ 0 & \varepsilon_{2t} \\ 0 & \varepsilon_{3t} \\ 0 & \varepsilon_{4t} \\ 1 & \varepsilon_{5t} \\ \varepsilon_{5t} \\ \varepsilon_{5t} \end{array}$	(A.1)
							0/	

Transition Equation:

Different specifications for each funding currencies are examined. Best model for all currencies is a common factor as a regime switching mean with an autoregressive idiosyncratic term. Thus, the AR (1) parameter of the model is zero:

$$F_t = \mu_{st} + \nu_t \tag{A.3}$$

Although equation A.3 is a tight assumption, restricting the AR parameter of the common factor, it decreases the likelihood value making the transition probabilities highly significant. The likelihood ratio test is used to test whether there is a difference between the restricted and unrestricted model. The test results favors for no difference. In vector notation, the measurement and transition equation will be written as:

$$Y_t = HB_t + \epsilon_t \tag{A.4}$$

$$B_t = \alpha_{st} + ZB_{t-1} + u_t \tag{A.5}$$

$$\binom{\omega_t}{u_t} \sim N \left(0, \quad \begin{pmatrix} R_t & 0\\ 0 & Q_t \end{pmatrix} \right)$$
 (A.6)

Appendix B: The Algorithm for Estimating the MS-Dynamic Factor

The filter for the state space model with Markov switching in the Appendix A is the combination of the Kalman Filter and the Hamilton Filter with appropriate approximations. Given the state space representation by the equations A.3 and A.4, the Markov switching dynamic factor is estimated by following these steps:

Run the Kalman Filter:

$$\beta_{t|t-1}^{(i,j)} = \alpha_j + Z_j \beta_{t-1|t-1}^i \tag{B.1}$$

$$P_{t|t-1}^{(i,j)} = Z_j P_{t-1|t-1}^i Z_j' + Q$$
(B.2)

$$\eta_{t|t-1}^{(i,j)} = Y_t - H_j \beta_{t|t-1}^i$$
(B.3)

$$f_{t|t-1}^{(n)} = H_j P_{t|t-1}^n H_j^1 + R$$
(B.4)

$$\beta_{t|t}^{(l,j)} = \beta_{t|t-1}^{(l,j)} + P_{t|t-1}^{(l,j)} H_j' \left[f_{t|t-1}^{(l,j)} \right] \quad \eta_{t|t-1}^{(l,j)}$$
(B.5)

$$P_{t|t}^{(i,j)} = (I - P_{t|t-1}^{(i,j)} H'_j \left[f_{t|t-1}^{(i,j)} \right]^{-1} H_j) \eta_{t|t-1}^{(i,j)}$$
(B.6)

where $\beta_{t-1|t-1}^{i}$ is an inference on β_{t-1} up to time t-1, given $S_{t-1} = i$; $\beta_{t|t-1}^{(i,j)}$ is an inference on β_t up to time t-1, given $S_t = j$ and $S_{t-1} = i$; $P_{t|t-1}^{(i,j)}$ is the mean square error matrix of $\beta_{t|t-1}^{(i,j)}$ conditional on $S_t = j$

j and $S_{t-1} = i$; $\eta_{t|t-1}^{(i,j)}$ is the conditional forecast error of Y_t based on information up to time t-1, given $S_t = j$ and $S_{t-1} = i$ and $f_{t|t-1}^{(i,j)}$ is the conditional variance of forecast error $\eta_{t|t-1}^{(i,j)}$.

2. Run the Hamilton Filter and calculate $\Pr[S_t, S_{t-1}|\psi_t]$ and $\Pr[S_t|\psi_t]$, given that ψ_t denote the vector of observations available as of time *t*.

3. Approximations: Using the probability terms in step 2, collapse *GXG* posteriors in equations B.5 and B.5 into *GX*1 using the following equations:

$$\beta_{t|t}^{(j)} = \frac{\sum_{i=1}^{G} \Pr[S_{t-1}=i, S_t=j|\psi_t] \beta_{t|t}^{(i,j)}}{\Pr[S_t=i|\psi_t]}$$
(B.7)

$$P_{t|t}^{j} = \frac{\sum_{i=1}^{G} \Pr[S_{t-1} = i, S_{t} = j|\psi_{t}] [P_{t|t}^{i,j} + (\beta_{t|t}^{j} - \beta_{t|t}^{(i,j)}) (\beta_{t|t}^{j} - \beta_{t|t}^{(i,j)})]}{\Pr[S_{t} = i|\psi_{t}]}$$
(B.8)

The conditional mean and the conditional variance of the AR (1) process is used as the initial values to start the Kalman Filter. For the Hamilton Filter, the steady state probabilities are used as initial values for the state probabilities. The parameters and probabilities are estimated by the approximate likelihood function:

$$LL = \ln[f(Y_1, Y_2, \dots, Y_T)] = \sum_{t=1}^T \ln[f(Y_t | \psi_{t-1})]$$
(B.9)

REFERENCES

Bhattarai, K. (2008) "An Empirical Study of Interest Rate Determination Rules," *Applied Financial Economics*, vol.18(4), p.327-343

Brunnermeier, M. K., Nagel, S., & Pedersen, L. H. (2008) "Carry Trades and Currency Crashes," *National Bureau of Economic Research*, (No. w14473). Retrieved from National Bureau of Economic Research http://www.nber.org/papers/w14473

Burnside, C., Eichenbaum, M. S. and Rebelo, S. (2011) "Carry Trade and Momentum in Currency Markets" *Annual Review of Financial Economics*, vol.3(1), December, p. 511–535

Chauvet, M. (1998) "An Econometric Characterization of Business Cycle Dynamics with Factor Structure and Regime Switching," *International Economic Review*, vol. 39(4), November, p. 969-996

Cheung, Y. W., Chinn, M. D., & Pascual, A. G. (2005) "Empirical Exchange Rate Models of the Nineties: Are any Fit to Survive?" *Journal of International Money and Finance*, vol.24(7), November, p. 1150-1175

Chinn, M. D. and S. Quayyum (2012) "Long Horizon Uncovered Interest Parity Re-assessed," *National Bureau of Economic Research*, (No. w18482). Retrieved from National Bureau of Economic Research website: http://www.nber.org/papers/w18482

Clarida, R., Gali J., & Gertler, M. (1998) "Monetary Policy Rules in Practice: Some International Evidence," *European Economic Review*, vol.42(6), p.1033-1067.

Engel, C., Mark, N. C., & West, K. D (2007) "Exchange Rate Models are not as Bad as You Think," *National Bureau of Economic Research*, (No. w13318).

Engel, C., Mark, N. C., & West, K. D. (2015) "Factor Model Forecasts of Exchange Rates," *Econometric Reviews*, vol.34(1-2), p.32-55.

Greenaway, R., Mark, N. C., Sul, D., & Wu, J. L. (2012) "Exchange Rates as Exchange Rate Common Factors," *HKIMR Working Paper*, No.21. Retrieved from Social Science Research Network website: http://ssrn.com/abstract=2138713

Hamilton, J. D. (1989) "A New Approach to the Economic Analysis of Nonstationary Time Series and the Business Cycle," *Econometrica: Journal of the Econometric Society*, vol. 57(2), March, p. 357-384

Fama, E. F. (1984) "Forward and Spot Exchange Rates," *Journal of Monetary Economics*, vol. 14(3), November, p. 319-338

Frankel, J. A. (1980) "Tests of Rational Expectations in the Forward Exchange Market," *Southern Economic Journal*, vol. 46(4), April, p.1083-1101

Jordà, Ò. and A. M. Taylor (2012) "The Carry Trade and Fundamentals: Nothing to Fear but FEER itself," *Journal of International Economics*, vol. 88(1), September, p. 74-90

Kim, C. J., & Nelson, C. R. (1999) "State-space Models with Regime Switching: Classical and Gibbssampling Approaches with Applications" (Vol. 2). Cambridge, MA: MIT press.

Li, M. (2011) "An Evaluation of Exchange Rate Models by Carry Trade," *Journal of Economics and International Finance*, vol. 3(2), February, p. 72-87

Lustig, H., Roussanov, N., & Verdelhan, A. (2011) "Common Risk Factors in Currency Markets," *Review of Financial Studies*, vol. 24(11), p. 3731-3777.

Meese, R. A. and K. Rogoff (1983) "Empirical Exchange Rate Models of the Seventies: Do They Fit out of Sample?" *Journal of international economics*, vol. 14(1), February, p. 3-24

Molodtsova, T. and D. H. Papell (2009) "Out-of-sample Exchange Rate Predictability with Taylor Rule Fundamentals," *Journal of International Economics*, vol. 77(2), April, p. 167-180

Österholm, P. (2005) "The Taylor Rule: A Spurious Regression?" *Bulletin of Economic Research*, vol.57(3), p. 217-247.

Stock, J. H., & Watson, M. W. (1989) "New Indexes of Coincident and Leading Economic Indicators," NBER *Macroeconomics Annual*, vol. 4, p. 351-409

Taylor, J. B. (1993) "Discretion versus Policy Rules in Practice," *In Carnegie-Rochester conference series on Public Policy*, vol. 39, December, p. 195-214

Verdelhan, A. (2015) "The Share of Systematic Risk in Bilateral Exchange Rates," *Journal of Finance, Forthcoming.* Retrieved from Social Science Research Network website: http://ssrn.com/abstract=1930516

BIOGRAPHY

Gokcen Ogruk is Assistant Professor of Economics at Texas Wesleyan University, School of Business and Professional Studies. She can be contacted at 1201 Wesleyan Street, Fort Worth, TX 76105. Phone: 8175314837. Email: gogruk@txwes.edu.