PISSN 2508-1640 EISSN 2508-1667 an open access journal
East Asian Economic Review vol. 22, no. 4 (December 2018) 467-505
http://dx.doi.org/10.11644/KIEP.EAER.2018.22.4.351

Foreign Exchange Return Predictability: Rational Expectations Risk Premium vs. Expectational Errors*

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We propose a simple identification scheme for the causes of the violations of uncovered interest parity. Our method uses the serial dependence patterns of excess returns as a criterion for judging performance of economic models. We show that a mean reverting component in excess returns, representing a violation of uncovered interest parity, mainly contributes to generating different serial dependence patterns of excess returns: rational expectations risk premium models tend to generate negative serial dependence of excess returns, while expectational errors models tend to generate positive serial dependence.

Keywords: Violations of Uncovered Interest Parity, Expectational Errors, Rational Expectations Risk Premium, Foreign Exchange Excess Returns, Serial Dependence
JEL Classification: F31, F37, G15

I. INTRODUCTION

Uncovered interest parity (UIP) states that the expected exchange rate change should be equal to the interest rate difference between the two countries and implies that when borrowing from home and lending to foreign, the cost of borrowing (home interest rate) should be on average the same as the revenue from the investment (foreign interest rate plus capital gain from currency transactions) under the assumptions of rational expectations and risk neutrality. That is, foreign exchange excess return defined by the revenue from the investment minus its cost is not predictable or the expected foreign exchange excess return must be zero, according to UIP. One typical way to test this hypothesis is to run a regression of exchange rate change on the interest

* This paper was supported by research funds of Chonbuk National University in 2017. This paper is based on part of our paper circulated under the title "The Forward Discount Puzzle: Identification of Economic Assumptions."

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differential and to investigate if the estimated the slope coefficient in the regression is equal to one. However, numerous empirical studies have presented strong evidence on the violations of this hypothesis: the estimated slope coefficient is less than one and negative very often.[1] The forward premium puzzle refers to such robust empirical findings on the predictability of foreign exchange excess returns [see, for example, Lewis (1995), Engel (1996), Chinn (2006), and Verdelhan (2010) for the survey and recent contributions]. Nevertheless, previous studies have not reached consensus about the causes of violations of UIP yet: Is the predictability due to the presence of the rational expectations risk premium in an efficient market or evidence of market inefficiency reflecting deviations from rationality?[2] This paper proposes a simple identification scheme for the two well-known explanations for violations of UIP.[3]

Since both the rational expectations risk premium and expectational errors are not observable in data, researchers have instead built economic models which generate them and investigate if their models can explain the violations of UIP based on a certain criterion. One popular criterion is Fama (1984)'s volatility relation derived from the return regression of exchange rate change on the interest rate differential: the

[1] Violations of UIP can occur if one of the UIP assumptions does not hold in data. The assumption of rational expectations implies that market participants efficiently use all the information available in predicting future exchange rates and thus foreign exchange excess returns are not predictable if market participants are risk neutral. However, if market participants are risk averse, the expected foreign exchange excess returns may not be zero even in efficient foreign exchange markets because they demand reward for holding risky assets. This non-zero expected excess return in efficient foreign exchange markets is called rational expectations risk premium. In particular, the concept of the risk premium in foreign exchange markets can be similarly interpreted as that of equity premium in stock markets. On the other hand, market participants may systematically under- or over-predict future exchange rates so that the market expectation persistently deviates from the rational expectation. This deviation which causes a violation of UIP is called expectational errors. We provide formal definitions of the rational expectations risk premium and expectational errors in Section II.

[2] There are the two popular explanations for the predictability of foreign exchange excess returns in the literature: rational expectations risk premium and expectational errors. For example, Alvarez, Atkeson, and Kehoe (2009) and Verdelhan (2010) relate the cause of the foreign exchange excess return predictability to the rational expectations risk premium. On the other hand, Froot and Frankel (1989), Frankel and Froot (1990a, 1990b), Mark and Wu (1998), Gourinchas and Tornell (2004), and Kim, Moon, and Velasco (2017) relate the cause to expectational errors.

[3] Froot and Frankel (1989) first addressed this identification issue using data obtained from the surveys of foreign exchange market participants on the forecasts of the future exchange rates. However, the use of survey data faces several criticisms such as measurement errors and the issues of cheap talks.

volatility of the rational expectations risk premium (the expected foreign exchange excess return) should be greater than that of the expected exchange rate change if the slope coefficient in the regression is less than one half.[4] This volatility relation implies that the rational expectations risk premium generated from economic models should be very volatile to explain the violations of UIP. As well-known, many economic models fail to generate such a high volatility miserably. However, several studies question the accuracy of the estimated slope coefficient in the regression and show that the estimates may not be so informative because its distribution is too wide and the magnitude of systematic estimation errors is large [see, for example, Baillie and Bollerslev (2000); West (2012); Moon and Velasco (2017)]. Specifically, Moon and Velasco (2017) show that the negative estimates in the regression, which have been linked to a higher volatility of the risk premium based on Fama's volatility relation, can even be generated from economic models where the unbiased hypothesis holds and time series properties of spot and forward rates are consistent with data and question the use of the estimated slope coefficients for judging the performance of economic models.

In this paper, instead, we use information implied by the economic models that restrict the relations between macroeconomic fundamentals and equilibrium expected foreign exchange excess returns. Specifically, we show that a mean reverting predictable component in foreign exchange excess returns, representing a violation of UIP, can generate different or even opposite serial dependence patterns of excess returns depending on the economic model assumptions. We then present empirical evidence on these serial dependence patterns using variance ratio tests for developed economies and use it as a criterion for judging the performance of the economic models. One advantage of our approach is that our estimation of the serial dependence of foreign exchange excess returns is not subject to the shortcoming that the previous studies above pointed out.

We show that a class of rational expectations risk premium models tends to generate 'negative' serial dependence of excess returns. This is mainly because macroeconomic fundamental variables are negatively related with the risk premium, which is a key relation in the risk premium models. Verdelhan (2010), for example, interpreted this negative relation in his model as counter-cyclical exchange risk premium. This class

[4] See Fama (1984), Lewis (1995), and Engel (1996) for the derivation of the volatility relation and its applications.

of economic models includes the typical monetary models with standard utility functions, the monetary general equilibrium model with asset market segmentation by Alvarez, Atkeson, and Kehoe (2009), and the external habit-persistence model with time-varying risk aversion by Verdelhan (2010). In particular, the latter two models are successful in generating highly volatile risk premium.[5] On the other hand, a class of models for expectational errors tends to generate 'positive' serial dependence in excess returns. The class includes the model of speculative bubbles by Frankel and Froot (1990a, 1990b), the noise trader model by Mark and Wu (1998), and the misperception models by Gourinchas and Tornell (2004). We argue that serial dependence patterns observed in data can be used as a necessary condition for judging the validity of an economic model of the expected excess return, in the sense that a valid model should be able to generate those patterns not only qualitatively but also quantitatively matched with data. Of course, we admit that examining serial dependence patterns in data may not be enough to reach a conclusion in favor of a particular explanation.

Using the variance ratio test developed by Lo and McKinlay (1988, 1989), we estimate serial dependence of foreign exchange excess returns against the US dollar over return horizons up to five years for two different sample periods of 1980-87 and 1988-2015. We find that foreign exchange excess returns strongly exhibit positive serial dependence over return horizons up to five years, consistent with the prediction of the expectational errors explanation, for the former sample period. However, excess returns tend to be unpredictable in the latter sample period, implying that the source of the predictability of foreign exchange returns is mainly related to the expectational errors of foreign exchange market participants. We consider these two sample periods following Kim, Moon, and Velasco (2017) in order to check if our identification is useful. They show that US monetary policy regimes affect the predictability of excess returns. In particular, they find that the strong predictability of foreign exchange excess

[5] As is well known, a representative-agent monetary model with standard utility functions cannot generate a highly volatile risk premium, while matching with very small variations of aggregate consumption data. To overcome this difficulty, researchers take largely two different approaches in the literature. One approach is to assume utility functions which make the marginal utility of consumption very sensitive to a small variation of consumption [see, for example, Verdelhan (2010)]. The other approach is to consider limited participation models where the marginal investor's consumption is not equal to aggregate consumption [see, for example, Alvarez, Atkeson, and Kehoe (2009)].

returns is mainly occurred in the former period and provide an explanation based on market participants' systematic errors on the prediction of the US federal reserves' monetary policy: During the early 1980s, market participants persistently expected that the fed would give its contractionary monetary policy up soon since the US economy was in recession. This explanation is consistent with the expectational errors hypothesis for the violation of UIP.

Kim, Moon, and Velasco (2017)'s explanation about the strong predictability of foreign exchange excess returns against the US dollar during the Volcker era and the unpredictability of excess returns during the post-Volcker era is based on the imperfect credibility of Volcker fed's contractionary monetary policy during the early 1980s. However, one may argue that international capital market integration may enforce the unpredictability of foreign exchange excess returns since the early 1990s, rather than the credibility of fed's monetary policy. In this paper, we test this possibility, controlling for the influence of the fed's monetary policy. That is, we conduct the same variance ratio test replacing the US dollar with the German mark as a base currency to eliminate the influence of common components in US dollar bilateral rates. We find that the serial dependence pattern of foreign exchange excess returns against the German mark is very different from that of excess returns against the US dollar, supporting Kim, Moon, and Velasco (2017)'s explanation. In addition, we also consider the possibility that the monetary policy regime change around the global financial crisis may affect the predictability of foreign exchange excess returns by dividing the post-Volcker era into two sample periods of 1988-2006 and 2007-2015. We find that the results are in general quite similar between the post-Volcker era and the period of 2007-2015, supporting the expectational error explanation that the monetary policy regime change based on the imperfect credibility of the US monetary policy mainly affects the predictability of foreign exchange excess returns against the US dollar.

The organization of the paper follows. Section II shows analytically that the two competing economic explanations generate opposite signs of the serial dependence of excess returns. Section III presents our empirical methods based on the variance ratio test and Section IV provides empirical results on the serial dependence patterns of foreign exchange excess returns. And Conclusions follow.

II. MODELS FOR TWO COMPETING EXPLANATIONS: RATIONAL EXPECTATIONS RISK PREMIUM VS. EXPECTATIONAL ERRORS

In this section, we consider the implication of general economic models for the serial dependence pattern of the expected foreign exchange excess returns. Specifically, we show that the sign of autocorrelations of foreign exchange excess returns can be used as a criterion for the validity of an economic model. To illustrate our argument, we first present the economic models of the two most popular explanations for the predictability of foreign exchange excess returns: rational expectations risk premium and expectational errors. We then show that they tend to generate opposite signs in the autocorrelation functions of those excess returns.

1. A General Setup for Exchange Rates

We consider a general setup for the exchange rate

$$s_t = \alpha E_t[\Delta s_{t+1}] + \alpha p_t^e - \alpha p_t + \varpi_t + w_t \tag{1}$$

where s_t denotes the log of the spot exchange rate, $p_t^e = E_t^m[\Delta s_{t+1}] - E_t[\Delta s_{t+1}]$ is the expectational error defined by the difference between the market expectation ($E_t^m[\cdot]$) and the rational expectation ($E_t[\cdot]$), p_t is the rational expectations risk premium which will be defined below, ω_t is the log of the real exchange rate, w_t is the linear combination of logs of fundamental variables such as money and output, and α is constant [see, for example, Frankel and Froot (1990b) and Engel and West (2005) for the derivation of the setup.]. ϖ_t represents a deviation from purchasing power parity (PPP) which is one of major building blocks in international macroeconomic models. Both p_t and p_t^e represent violations of UIP which is also one of major building blocks in international macroeconomic models.

Deviations from UIP are given by

$$E_t[\Delta s_{t+1}] - (i_t - i_t^*) = d_t, \tag{2}$$

where d_t represents violations of UIP (p_t, p_t^e, or combination of both). Note that $s_{t+1} - s_t + i_t^*$ is the revenue from holding one-period foreign currency denominated bond and i_t is the revenue from holding one-period domestic currency denominated bond. If an investor borrows in domestic bond to finance the foreign investment, the excess return on foreign currency denominated bond (or the foreign exchange excess return against the home currency denominated bond) is $s_{t+1} - s_t + i_t^* - i_t$. If the market expectation is rational and there is no risk premium, then the expected excess return, $E_t[\Delta s_{t+1}] - (i_t - i_t^*)$ is zero, i.e., UIP holds. Non-zero values of d_t imply deviations from UIP. In the typical monetary models, equation (1) is derived from home and foreign money demands combined with equation (2) [see, e.g., Engel and West (2005); Obstfeld and Rogoff (2003) for the rational expectations models, and Frankel and Froot (1990b) for the expectational errors models].

We assume that the process for the linear combination of fundamental variables w_t follows

$$\Delta w_t = \rho \Delta w_{t-1} + \eta_t \tag{3}$$

where η_t represents a stochastic disturbance with mean zero and variance σ_η^2. If $\rho = 0$, then the fundamental process follows a random walk. The introduction of more complicated fundamental processes would not change our main results below since the predictability of excess returns is mainly related to the deviations from UIP. Therefore, considering equation (3) is enough for our objectives.

The system of equations (1)-(3) is quite general to cover many exchange rate models in the literature. For example, with $\rho = 0$, the spot exchange rate can be described by the combination of a random walk fundamental and some persistent stationary components due to the deviations from UIP, mirroring a well-known fads model used for studying the predictability of stock returns in Fama and French (1988) and Poterba and Summers (1988).

We now examine how either the rational expectations risk premium, p_t, or the expectational error, p_t^e, is determined in the structural economic models. One key feature of the process for these deviations from UIP in those models is that the series follows a stationary process. Further, those models can be reduced to equations (1)-(3) and the equation for the process of either p_t or p_t^e which will be specified in detail below. With these four equations, one can pin down the autocorrelations of foreign exchange excess returns. The key idea of the present paper is to provide a simple criterion to identify the unobservable components of the expected excess returns such as the rational expectations risk premium or the expectational error, using the autocorrelations of foreign exchange excess returns.

2. Rational Expectations Risk Premium

We examine the sign of the autocorrelations of foreign exchange excess returns using two models for the rational expectations risk premium. One is the general equilibrium monetary model with an endogenous asset market segmentation by Alvarez, Atkeson, and Kehoe (2009); the other is the external habit persistence model by Verdelhan (2010). We mainly derive the equilibrium (expected) excess returns from these models in the text and relegate the detailed presentation to the Technical Appendix. Nevertheless, we discuss the key mechanisms and assumptions of all these models to identify the link between the time series behavior of the risk premium and the sign of serial dependence of foreign exchange excess returns. We begin with deriving the risk premium from a currency pricing setting whose definition is exactly applied to all these models.

Assume that there are no arbitrage opportunities in an economy so that a pricing kernel exists. Let m_{t+1} be the pricing kernel for home assets and m^*_{t+1} be the pricing kernel for foreign assets. These pricing kernels imply that any asset purchased in period t with a home currency return of R_{t+1} between periods t and $\mathrm{t}+1$ and any asset purchased with a foreign currency return of R^*_{t+1} satisfy the Euler equations, respectively,

$$1 = E_t[m_{t+1}R_{t+1}], \qquad 1 = E_t[m^*_{t+1}R^*_{t+1}]. \tag{4}$$

In complete asset markets, there exists the unique pricing kernel m that satisfies equation (4). Although the pricing kernels are not unique in incomplete asset markets, they can be chosen to satisfy the same equations [see, for example, Backus, Foresi, and Telmer (2001, Proposition 1)]. Then, in foreign exchange rate models the pricing kernel for foreign assets m^*_{t+1} can be related to m_{t+1} in the following way,

$$m^*_{t+1} = \frac{m_{t+1}S_{t+1}}{S_t}, \tag{5}$$

where S_t denotes the spot exchange level. The change in the log of the exchange rate is

$$\mathrm{s}_{\mathrm{t+1}} - \mathrm{s}_{\mathrm{t}} = \ln m_{t+1}^{*} - \ln m_{t+1}, \tag{6}$$

where $s_t = \ln S_t$. By taking mathematical expectations conditional on time t information set, the expected exchange rate depreciation can be derived by

$$E_t[\mathrm{s}_{\mathrm{t+1}} - \mathrm{s}_{\mathrm{t}}] = E_t[\ln m_{t+1}^{*} - \ln m_{t+1}], \tag{7}$$

In the typical models for the rational expectations risk premium, two assets, a one-period home currency denominated bond and a one-period foreign currency denominated bond, are traded in the economy. And the returns for the bonds are gross interest rates: $R_{t+1} = 1 + i_t$ and $R_{t+1}^{*} = 1 + i_t^{*}$ where i_t (i_t^{*}) is the home (foreign) interest rate between period t and $\mathrm{t} + 1$. Then, from equation (4), the log of the price of a one-period home currency denominated bond and that of one-period foreign currency denominated bond can be expressed as

$$-i_t = \ln E_t[m_{t+1}], \qquad -i_t^{*} = \ln E_t[m_{t+1}^{*}]. \tag{8}$$

Assume that market expectation is rational. Using the expressions for the expected exchange rate change in equation (7) and for the interest rates in equation (8), we can define the foreign exchange risk premium by[6]

$$\begin{aligned} p_t = E_t[\Delta s_{t+1}] + i_t^{*} - i_t = (\ln E_t[m_{t+1}] - E_t[\ln m_{t+1}]) \\ -(\ln E_t[m_{t+1}^{*}] - E_t[\ln(m_{t+1}^{*})]). \end{aligned} \tag{9}$$

Note that the foreign exchange risk premium is the expected excess return under the assumption of the rational market expectation. If both m_{t+1} and m_{t+1}^{*} follow a conditional log normal distribution, then

$$p_t = \frac{1}{2}(Var_t[\ln m_{t+1}] - Var_t[\ln m_{t+1}^{*}])$$

[6] Two popular definitions for the risk premium are interchangeably used in the literature. For example, several studies define the risk premium by $p_t = E_t[\Delta s_{t+1}] + i_t^{*} - i_t$ like us [see, for example, Alvarez, Atkeson, and Kehoe (2009) and Verdelhan (2010)], while the other studies define it by $p_t = i_t - i_t^{*} - E_t[\Delta s_{t+1}]$ [see, for example, Froot and Frankel (1989), Engel (1996), Backus, Foresi, and Telmer (2001), and Obstfeld and Rogoff (2003)]. However, this would not change the result because the sign of p_t in equations (1)-(2) will change accordingly.

Note that the definition for the risk premium in (9) can be applied to any rational expectations risk premium models, although its main determinants depend on specific models. And without loss of generality, the process for the risk premium can be written in the following way:

$$p_t = E_{t-1}[p_t] + \varepsilon_t \tag{10}$$

where ε_t is an i.i.d. random variable with mean zero and variance σ_ε^2.

For any economic models, the foreign exchange excess returns can be defined by

$$r_{t+1}^e = s_{t+1} - s_t + i_t^* - i_t = s_{t+1} - f_t = s_{t+1} - E_t[s_{t+1}] + E_t[s_{t+1}] - f_t$$

where f_t is the one-period forward exchange rate and the second equality is derived using covered interest parity which states $f_t = i_t - i_t^* + s_t$. Then, using equations (1)-(3) and (10) and assuming that market expectation is rational ($p_t^e = 0$), the foreign exchange excess returns can be derived by

$$r_{t+1}^e = fd_{t+1} + fp_{t+1} + p_t \tag{11}$$

where constant terms are omitted for simplicity. The first two terms in the right-hand side of equation (11) are forecasting errors, $s_{t+1} - E_t[s_{t+1}]$, which contain two disturbance terms: fd_{t+1} is a function of stochastic disturbance η_{t+1} in the fundamental process and fp_{t+1} is a function of stochastic disturbance ε_{t+1} in the risk premium process. For example, fd_{t+1} is the difference between disturbances to home and foreign money growth rates in Obstfeld and Rogoff (2003) and Alvarez, Atkeson, and Kehoe (2009), and the difference between disturbances to home and foreign consumption growth rates in Verdelhan (2010).[7] Equation (11) implies that the forecasting errors between time t and $\mathrm{t}+1$ will be correlated with the future values of p_t, which reflects a feedback from forecasting errors to future expected excess returns. As will be shown later, this feedback provides an identification device for the sign of autocorrelations of excess returns. Note that in the absence of the risk premium, the forecasting errors are reduced to the stochastic

[7] Verdelhan (2010) abstract from money and inflation and focuses on a real risk. So, the currency excess return in equation (11) should be interpreted accordingly.

disturbances in the fundamental process, fd_{t+1}.

To understand the feedback mechanism in detail, we decompose the covariance of two consecutive excess returns between $\mathrm{t}+1$ and $\mathrm{t}+2$ by

$$\mathrm{Cov}(r_{t+1}^e, r_{t+2}^e) = \mathrm{Cov}(fd_{t+1}, \varepsilon_{t+1}) + \mathrm{Cov}(fp_{t+1}, \varepsilon_{t+1}) + \mathrm{Cov}(p_t, E_t[p_{t+1}]) \tag{12}$$

where $\mathrm{Cov}(fd_{t+1}, \varepsilon_{t+1})$ denotes the covariance between innovations to the fundamentals and those to the risk premium at time $\mathrm{t}+1$. We investigate how each of the three components on the right hand side of equation (12) contributes to the determination of the sign of $\mathrm{Cov}(r_{t+1}^e, r_{t+2}^e)$. First, all the models considered generate either a negative or a zero value of $\mathrm{Cov}(fd_{t+1}, \varepsilon_{t+1})$ which captures the relation between economic fundamentals and the risk premium.[8] For example, Alvarez, Atkeson, and Kehoe (2009) built a model which is driven by exogenous shocks to the growth rates of money supply in each country [the difference between home and foreign money supply in their model can be interpreted as the economic fundamental, w_t, in our setup]. They show that a change in the home money growth rate is negatively related to p_t if the money growth rate is persistent, and uncorrelated with p_t if the money growth rate is i.i.d. [see equation (39) in Alvarez, Atkeson, and Kehoe (2009)]. Verdelhan (2010) built an external habit persistent model which is driven by exogenous i.i.d. shocks to the growth rates of consumption in each country [the difference between home and foreign consumption in their model can be interpreted as the economic fundamental w_t with $\rho = 0$ in our setup]. His model also generates the negative value of $\mathrm{Cov}(fd_{t+1}, \varepsilon_{t+1})$ whose value is interpreted as a counter-cyclical risk premium. As shown in the Technical Appendix, the negative sign of $\mathrm{Cov}(fd_{t+1}, \varepsilon_{t+1})$ is one of the key conditions that generate negative autocorrelations of excess returns in those risk premium models. Second, in all the models, the sign of $\mathrm{Cov}(fp_{t+1}, \varepsilon_{t+1})$ is by construction either negative or zero. In the typical monetary models, for example, the negative sign of $\mathrm{Cov}(fp_{t+1}, \varepsilon_{t+1})$ can be easily checked from equations (1)-(3) and (10). Alvarez, Atkeson, and Kehoe (2009) impose that exchange rate follows a random walk in their calibration, implying that the covariance is zero. Finally, in all the models, $\mathrm{Cov}(p_t, E_t[p_{t+1}])$ is either positive or

[8] Campbell (1991) also derives this expression from the present value of stock prices with the AR(1) expected excess return process.

zero, depending on the persistence of the risk premium: if the risk premium is i.i.d., then $E_t[p_{t+1}]$ is a constant. Although the absolute relative magnitude between the sum of the first two quantities and the last one in the right-hand side of equation (12) is model specific, we find that the total sum is negative in all the models considered in the paper. For expositional simplicity, we provide our calculations in the Technical Appendix.

We now examine the behavior of the foreign excess return over long horizons [see, for example, Fama and French (1988)]. This exercise will provide further information about the behavior of expected excess returns. The long-horizon effects can be easily deduced from the following relation for the covariance between r^e_{t+1} and r^e_{t+1+q} for $q \geq 1$

$$\mathrm{Cov}\left(r^e_{t+1}, r^e_{t+1+q}\right) = \varphi^{q-1}\mathrm{Cov}(r^e_{t+1}, r^e_{t+2}) \tag{13}$$

where φ^{q-1} summarizes the long-horizon predictability of the excess return. For deriving equation (13), we assume that $E_t[p_{t+1}] = \varphi p_t$ where $\varphi < 1$. Equation (13) shows that the sign of $\mathrm{Cov}\left(r^e_{t+1}, r^e_{t+1+q}\right)$ is the same as that of $\mathrm{Cov}(r^e_{t+1}, r^e_{t+2})$ and implies that the long horizon predictability critically depends on the persistence of the rational expectations risk premium. As Fama and French (1988) shows, the accumulation of these autocovariances can induce strong autocorrelations over long horizons, which may not be clearly captured over short horizons, in particular, when φ is close to one. Therefore, examining the autocorrelation patterns of excess returns over long horizons provides a clearer picture for the presence of a mean reverting component in foreign exchange excess returns, which is related to the deviations from UIP.

In sum, we conclude that the models for the rational expectations risk premium tend to produce a negative autocorrelation of excess returns and the magnitude of these negative autocorrelations tends to decrease over the return horizon q. However, we emphasize that finding empirical evidence against the prediction of those risk premium models does not necessarily imply that the rational expectations hypothesis itself is rejected. Rather, our above analysis suggests that empirical evidence on the serial dependence pattern of excess returns may offer a criterion to judge the performance of economic models and a guidance towards a more plausible model for the data. For example, our analysis shows that the sign of $\mathrm{Cov}(fd_{t+1}, \varepsilon_{t+1})$ is tightly linked to the sign of serial dependence of excess returns in the risk premium models.

3. Expectational Errors

In this subsection, we present a model of expectational errors following Frankel and Froot (1990b). In the model, there are three types of risk-neutral agents: one is portfolio managers who participate in currency transactions; the other two are fundamentalists and chartists who are merely issuing their forecasts for the manager.[9] The expectation of the portfolio managers is equal to the market expectation given by

$$E_t^m[s_{t+1}] = (1-\lambda)E_t^f[s_{t+1}] + a\lambda E_t^c[s_{t+1}]) \tag{14}$$

where $E_t^f[\cdot]$ is the expectation of the fundamentalists, $E_t^c[\cdot]$ is the expectation of the chartists, and $0 < \lambda < 1$. The weight λ is assumed to be exogenously given and related to the sign of serial dependence of excess returns as shown below. The expectation of the fundamentalists is assumed to be regressive,

$$E_t^f[\Delta s_{t+1}] = -\theta(s_t - \bar{s}_t), \tag{15}$$

where $\theta > 0$ is the expected adjustment speed of s_t toward to $\bar{s}_t$ and $\bar{s}_t$ is a long-run equilibrium exchange rate level defined by inflation differentials between home and foreign country. This assumption is consistent with Dornbusch (1976) and requires that the fundamentalists anticipate future depreciation if the current exchange rate is above the long run equilibrium level. The expectation of the chartists is assumed to be of the form of distributed lags,

$$E_t^c[\Delta s_{t+1}] = -g\Delta s_t, \tag{16}$$

where g is assumed to be greater than or equal to zero. If $g = 0$, then the chartists expect that the exchange rate follows a random walk; if $g > 0$, then the chartists anticipate future depreciation of the currency toward its previous predicted level after

[9] This assumption is different from the noise trader model of Mark and Wu (1998), which is built on the idea of marketplace-aggregation. See, Frankel and Froot (1990b) for the detailed discussion.

observing a currency appreciation. If $g < 0,$ then the chartists have a bandwagon expectation. And we rule out this possibility in our paper. Suppose that the real exchange rate, ϖ_t, follows an AR(1) process

$$\varpi_t = (1-\psi)\bar{\varpi} + \psi\varpi_{t-1} + \nu_t \tag{17}$$

where $0 \leq \psi < 1$ and υ_t follows an i.i.d. Normal distribution with mean zero and variance σ_ν^2. Combining equations (1)-(3) and (14)-(17), we can derive the one-period excess return between time t and $t+1$,

$$r_{t+1}^e = \frac{1}{1+\alpha\lambda g}\eta_{t+1} + \frac{1-\alpha(1-\lambda)\theta}{1+\alpha\lambda g}\nu_{t+1} - p_t^e \tag{18}$$

where we assume $\rho = 0$ in the fundamental process (3) for simplicity, the first two terms in the right-hand side of equation (18) are forecasting errors. These errors correspond to $fd_{t+1} = \frac{1}{1+\alpha\lambda g}\eta_{t+1}$ and $fp_{t+1} = \frac{1-\alpha(1-\lambda)\theta}{1+\alpha\lambda g}\nu_{t+1}$, respectively, analogous to the previous subsection. The expectational error is

$$p_t^e = -\{\frac{-(1-\psi)+(1-\lambda)\theta(\alpha(1-\psi)+(1+\alpha\lambda g)}{1+\alpha\lambda g}\varpi_t + \frac{\alpha\lambda g+\lambda g(1+\alpha\lambda g)}{1+\alpha\lambda g}\Delta s_t\} \tag{19}$$

Here, we choose the value of θ so that the fundamentalists' expectation can be rational if $\lambda = 0$. Under this condition, we find that $\mathrm{Cov}(fd_{t+1} + fp_{t+1}, p_{t+1}^e)$ is positive for a broad range of parameter values. For example, suppose PPP holds so that ϖ_t is constant. Then, it is immediate to show that the covariance is positive. Or suppose that $g = 0$, that is, the chartists believes that the spot exchange rate follows a random walk. Then, the covariance is positive for sufficiently large values of ψ, consistent with the data.

We also find that the noise trader model of Mark and Wu (1998), based on De Long, Shleifer, Summers, and Waldmann (1990a), tends to generate positive serial dependence in foreign exchange excess returns for the range of parameter values considered in their paper. We do not provide further detailed results since the calculation is straightforward. See, for example, equations (12), (22), and (29) in Mark and Wu (1998). We further find that Gourinchas and Tornell (2004)'s expectational error model which intends to explain both the delayed overshooting puzzle and the forward premium puzzle generates positive serial dependence of excess returns. For conserving the space, we relegate the presentation of the model as well as the calculation of autocorrelation functions of foreign exchange excess returns generated from the model to the Technical Appendix. Note that Kim, Moon, and Velasco (2017)'s explanation on their empirical findings are based on Gourinchas and Tornell (2004)'s expectational error model where agents systematically make errors in perceiving interest rate innovations as more transitory than as they actually are.

In sum, we conclude that models for expectational errors tend to generate positive autocorrelations of excess returns. These results are consistent with the implications of the noise trader models by De Long, Shleifer, Summers, and Waldmann (1990b) for the serial dependence pattern of stock returns.

III. EMPIRICAL FRAMEWORK

1. *Empirical Method*

Our main goal in this section is to present an empirical method which can be used to estimate the serial dependence patterns of foreign excess returns over return horizon q. For this, we employ the serial dependence test based on the variance ratio statistic, developed by Lo and McKinlay (1988, 1989).

We define the population variance ratio $\mathrm{VR(q)}$ by

$$\mathrm{VR(q)} = \frac{Var(\sum_{i=0}^{q-1} r_{t+1+i}^{e})}{qVar(r_{t+1}^{e})} = 1 - 2\sum_{i=0}^{q-1}\left(1 - \frac{i}{q}\right)\gamma(i), \tag{20}$$

where q represents a return horizon and $\gamma(i) = \mathrm{Cov}(r_{t+1}^{e}, r_{t+1+i}^{e})/\mathrm{Var}(r_{t+1}^{e})$ denotes the autocorrelation of excess returns between t and $\mathrm{t + i}$. All autocorrelations must be zero under the null hypothesis of unpredictability of excess returns. So, $\mathrm{VR(q)}$ must be equal to one for each q if excess returns are not serially correlated. If the returns are positively (negatively) autocorrelated, $\mathrm{VR(q)}$ should be greater (less) than one.

Our test for the null hypothesis of no serial dependence of foreign exchange excess return (or the UIP hypothesis) is based on the t-values of the estimated variance ratios for each return horizon q, constructed by Lo and McKinlay (1988):

$$\mathrm{M(q)} = \frac{\sqrt{nq}(\widehat{VR}(q)-1)}{2(2q-1)(q-1)/3q} \tag{21}$$

where $\widehat{\mathrm{VR}}(q)$ is the estimated variance ratio for each q (see Lo and McKinlay (1988, p. 47) for the derivation). $\widehat{\mathrm{VR}}(q)$ is calculated by

$$\widehat{\mathrm{VR}}(q) = \frac{\sum_{t=q}^{T}(r_{t+1-q}^{e} + \cdots + r_{t+1-q}^{e} - q\bar{r}^{e})/m(q)}{\sum_{t=1}^{T}(r_{t}^{e} - q\bar{r}^{e})/m(1)}$$

where $\bar{r}^e$ is the sample mean of excess return $r_1^e, \cdots, r_T^e$ and $\mathrm{m(q)} = (\mathrm{T} - \mathrm{q} + 1)\left(1 - \frac{q}{T}\right)$ corrects the biases in the variance estimator. Variance ratio tests are more appropriate for our objective than other serial dependence tests such as portmanteau methods because they provide direct information on the sign of the serial dependence over return horizons and have good power properties (see, for example, Lo and McKinlay (1989) and Moon and Velasco (2013)).

As well known, the asymptotic tests based on variance ratios are liable to have important size distortions for several reasons. For example, the distribution of variance ratios is asymmetric because they are bounded by 0 from below and that using large q compared with sample size T may affect the finite sample properties of estimates of the standard deviation of variance ratios. Considering this difficulty, we obtain critical values using the parametric bootstrap procedure described in Moon and Velasco (2013), which leads to better approximations to the actual joint distribution of the variance ratio deviations from one than methods based on asymptotic results.

We perform the variance ratio test on one-month foreign exchange excess returns against the US dollar (USD) using monthly observations of spot and one-month forward exchange rates. Examining statistics at q=2 may be enough if the main objective is to judge the rejection or non-rejection of the UIP hypothesis. But the variance ratio test provides additional information helping us to understand the reasons for the rejections of the null hypothesis as discussed in the previous section.

2. Data

Our sample includes spot prices of USD against the Austrian schilling (ATS), the Belgian franc (BEF), the Canadian dollar (CAD), the Swiss franc (CHF), the Deutsche mark (DEM), the Danish krone (DKK), the Spanish peseta (ESP), the French franc

(FRF), the British pound (GBP), the Irish pound (IEP), the Italian lira (ITL), the Japanese yen (JPY), the Dutch guilder (NLG), the Portuguese escudo (PTE), and the Swedish krona (SEK). It also includes one-month forward prices of USD against the corresponding currencies. For the currencies of the member countries of the European Monetary Union (EMU), the sample period ends in 1998. For other currencies, the sample period ends in 2015.

Kim, Moon, and Velasco (2017) study the impacts of US monetary policy on exchange rates and show that the influence of the Volcker monetary policy regime is so immense that it contaminates the results for the entire sample period and thus mislead to a false conclusion. Taking into account of the results of their study, we control for the influence of the particular monetary policy regime and consider the following two sample periods: one sample period spans over 1980:01-1987:12 during which Paul Volcker was chairman of the US Federal Reserve and is called the Volcker era. The other period spans over 1988:01-1998:12 for the currencies of the member countries of the EMU and 1990:01-2015:01 for the other currencies, and is called the post-Volcker era.[10]

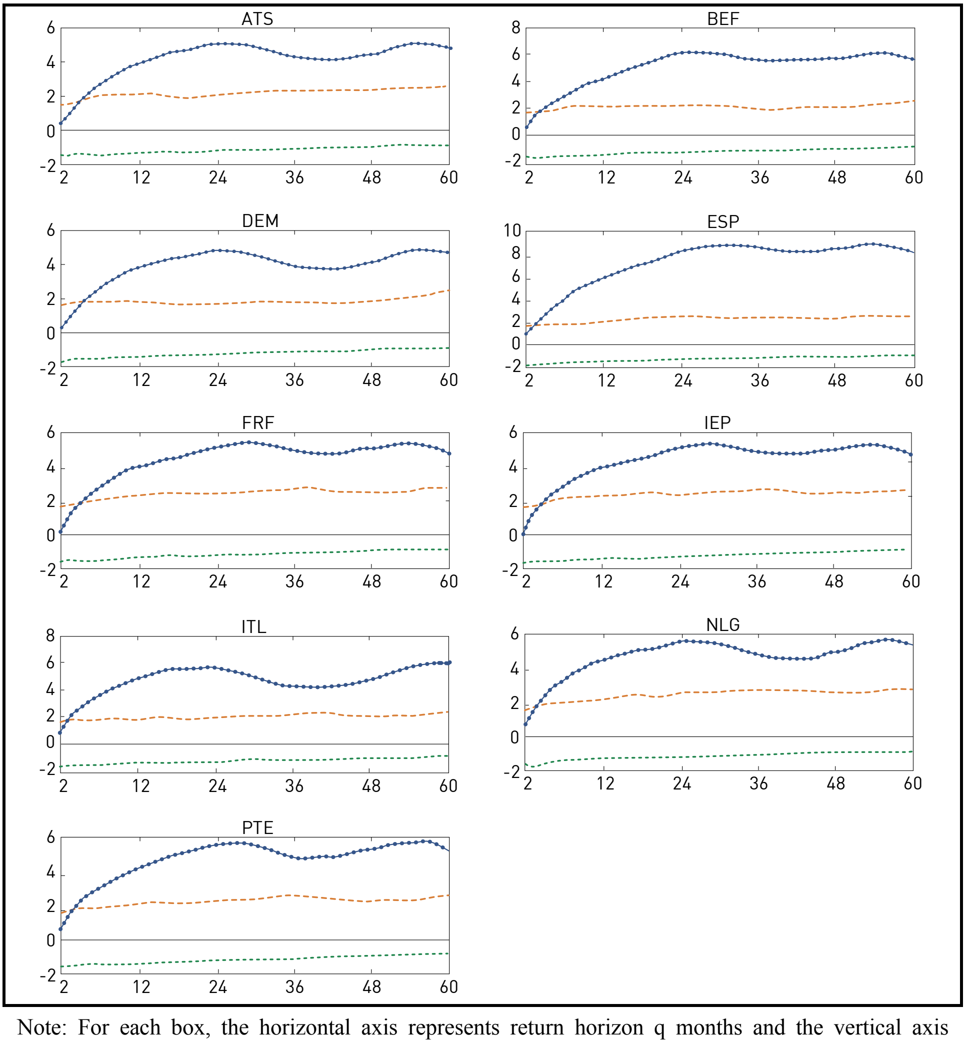
For our empirical study, we use monthly spot and one-month forward exchange rates obtained from two sources due to the data availability. First, we obtain the spot prices of as well as the one-month forward prices of USD against foreign currencies from the dataset of Burnside (2011). The sample period of his dataset spans over 1980-2011. In order to extend the sample period of Burnside (2011), we obtain those prices from the database of Datastream. Unfortunately, Datastream does not provide those prices of USD against the currencies of the member countries of the (EMU) any longer. Further, Datastream provides the forward prices since 1990. Considering them, we combine the two datasets. For the Volcker era, we use the dataset of Burnside (2011) and for the post-Volcker era, we use the dataset of Burnside (2011) for the currencies of the member countries of the EMU and the data from Datastream for the other currencies.

[10] Due to the data availability, we consider 1990:01 as the starting month for the post-Volcker era for the currencies of non-EMU member countries, instead of 1988:01.

IV. EMPIRICAL RESULTS

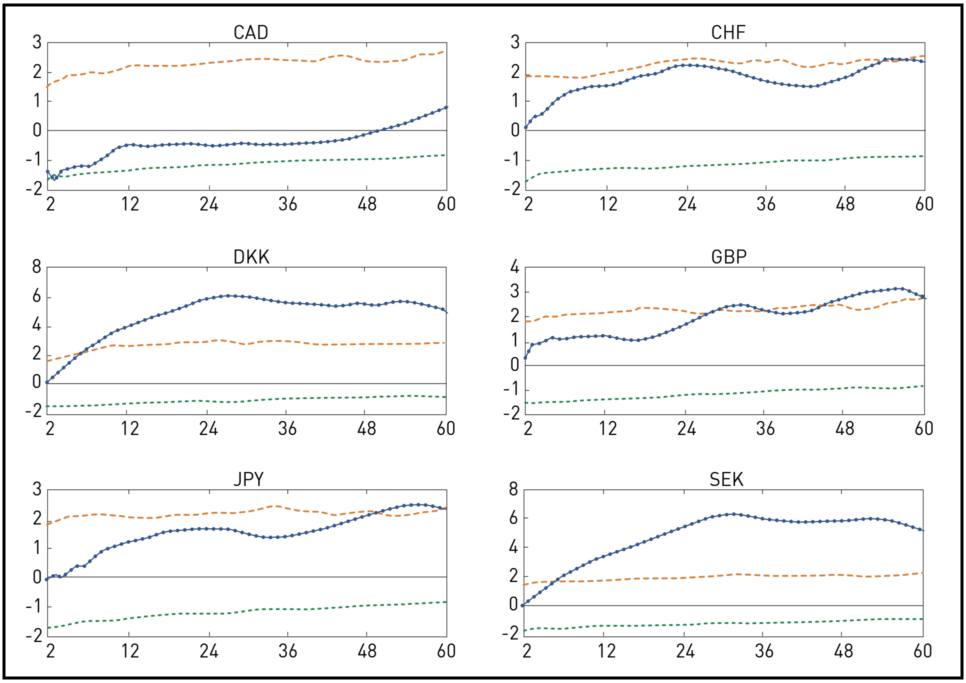
1. Main Results

Figure 1. Patterns of t-statistics of the Estimated Variance Ratios for One-month Excess Returns for the EMU Member Currencies Against the US Dollar During the Volcker Era (1980-87)



Note: For each box, the horizontal axis represents return horizon q months and the vertical axis represents the t-statistic of the estimated variance ratio M(q) defined in equation (21) for one-month excess returns.

Figure 2. Patterns of t-statistics of the Estimated Variance Ratios for One-month Excess Returns for the Non-EMU Member Currencies Against the US Dollar During the Volcker Era (1980-87)



See Note in Figure 1.

Figures 1-4 present the results regarding the serial dependence patterns of foreign exchange excess returns against the US dollar, which can be used to judge a validity of an economic model and thus helpful to understand the reasons for violations of UIP. Each figure shows how the t-statistics of estimated variance ratios, defined in equation (21), evolve with respect to the return horizon q (months). The line with circles is the locus of t-statistics with q and the two dotted lines correspond to 5 and 95% percentiles of the simulated bootstrap empirical null distribution of no predictability of foreign exchange excess returns, constructed from 5,000 bootstrap samples using the parametric bootstrap method.

First, we find that foreign exchange excess returns exhibit very strong positive serial dependence patterns over return horizons q during the Volcker era. As displayed in Figure 1, the t-statistics of estimated variance ratios for the currencies of the EMU member countries are positive and much greater than the critical values at the 95 percentile of the empirical distribution over the five-year horizon, implying that the null hypothesis of no predictability of foreign exchange excess returns is strongly rejected at the right tail. Specifically, the t-statistics keep increasing over the entire aggregation values q exceptionally with a small decrease between around q=24 and 48 months, although the t-statistics are inside the band with the critical values of 5% and 95% over very small values of qs,. This implies that the power of the variance ratio test increases as q further increases and illustrates the advantage of our identification scheme which can be applied to longer return horizons. When a predictable component in foreign exchange excess returns is very persistent, first differences in excess returns behave much like random increments over very small values of qs. However, as q increases, they behave less like random increments so that the predictable component can be detected more easily for a longer return horizon. See, for example, Fama and French (1988) who used this property for studying the predictability of US stock returns.

Unlike the results for the currencies of the member of the EMU, the serial dependence pattern for the currencies of the non-EMU member countries is different across the currencies as shown in Figure 2. We find the strong positive serial dependence patterns over the return horizons for DKK, GBP, and SEK, similar to the EMU currencies. But for CAD, CHF, and JPY, we find that the t-statistics are inside the band with the critical values of 5% and 95% over most return horizons, suggesting that those t-values are not statistically significant.

Second, we find that the predictability of excess returns becomes very weak in the post-Volcker era. As displayed in Figure 3 and 4, the t-statistics of the estimated variance ratios are inside the band with the critical values of 5% and 95% over all return horizons q for almost all currencies, suggesting that we are not able to reject the null hypothesis of no predictability of excess returns. JPY and SEK are exceptions. For both JPY and SEK, the t-values are slightly greater than the critical values at the 95 percentile of the empirical distribution over small values of q, suggesting that excess returns may exhibit positive serial dependence over some return horizons.

Overall, we find that foreign exchange excess returns against the US dollar are strongly predictable during the Volcker era but tend to be unpredictable during the post-Volcker era. These results are consistent with the findings of Kim, Moon, and Velasco (2017). More importantly, the positive serial dependence patterns of excess returns over return horizons during the Volcker era can be interpreted as evidence against the rational expectations risk premium hypothesis and in favor of the expectational error hypothesis. Interestingly, our findings on the serial dependence patterns of foreign exchange excess returns against the US dollar are consistent with Kim, Moon, and Velasco (2017)'s explanation that imperfect credibility of the Volcker disinflation policy held by public during the early 1980s is responsible for the predictability of foreign exchange excess returns against the US dollar and the credibility of the US monetary policy during the post-Volcker era corresponds to the unpredictability of foreign exchange excess returns.

2. Robustness

Figure 3. Patterns of t-statistics of the Estimated Variance Ratios for One-month Excess Returns for the EMU Member Currencies Against the US Dollar During the Post-Volcker Era (1988-98)

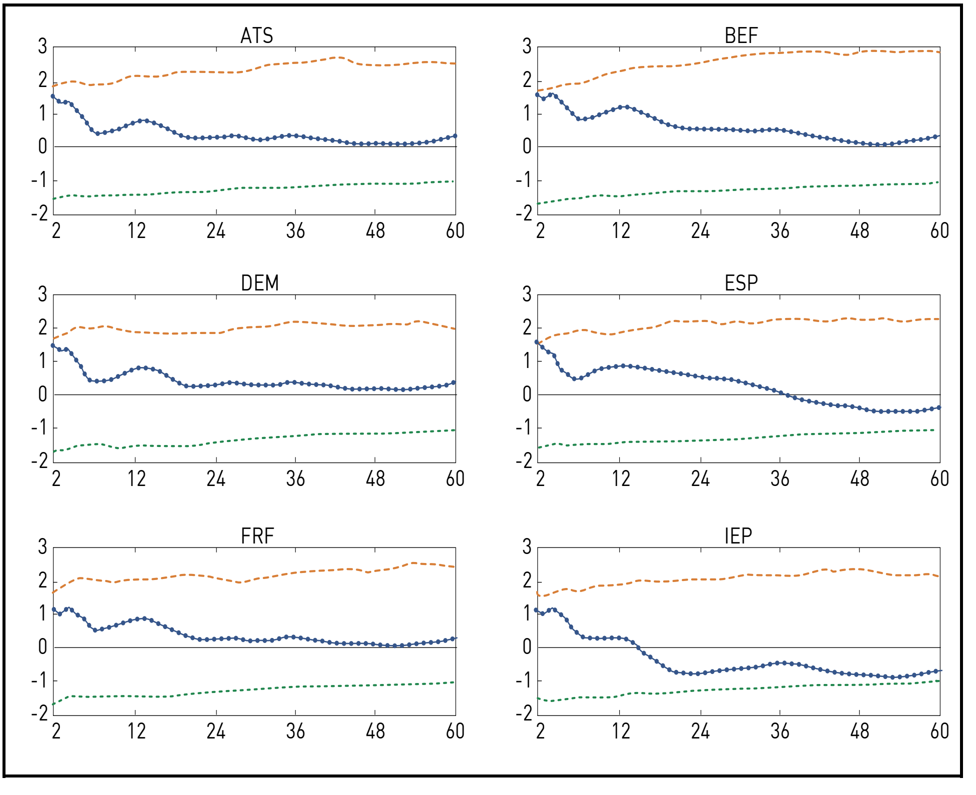
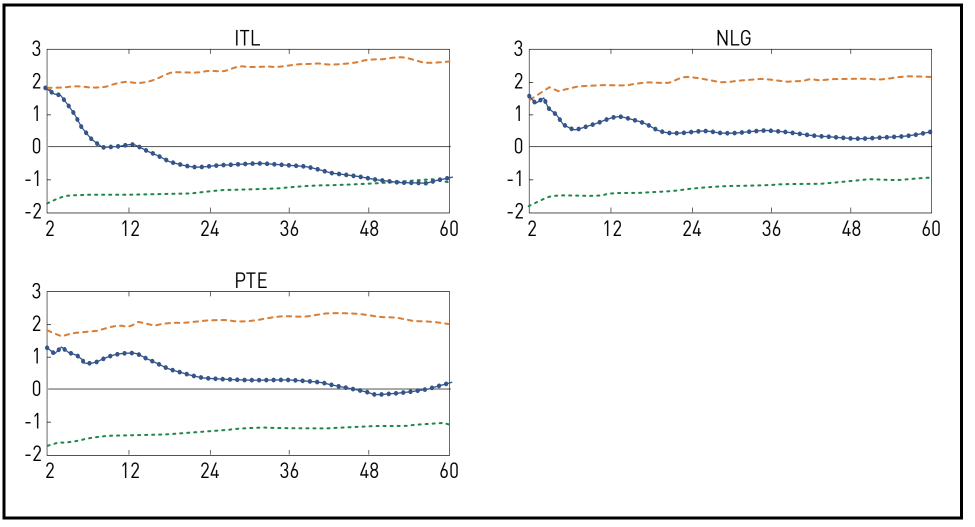


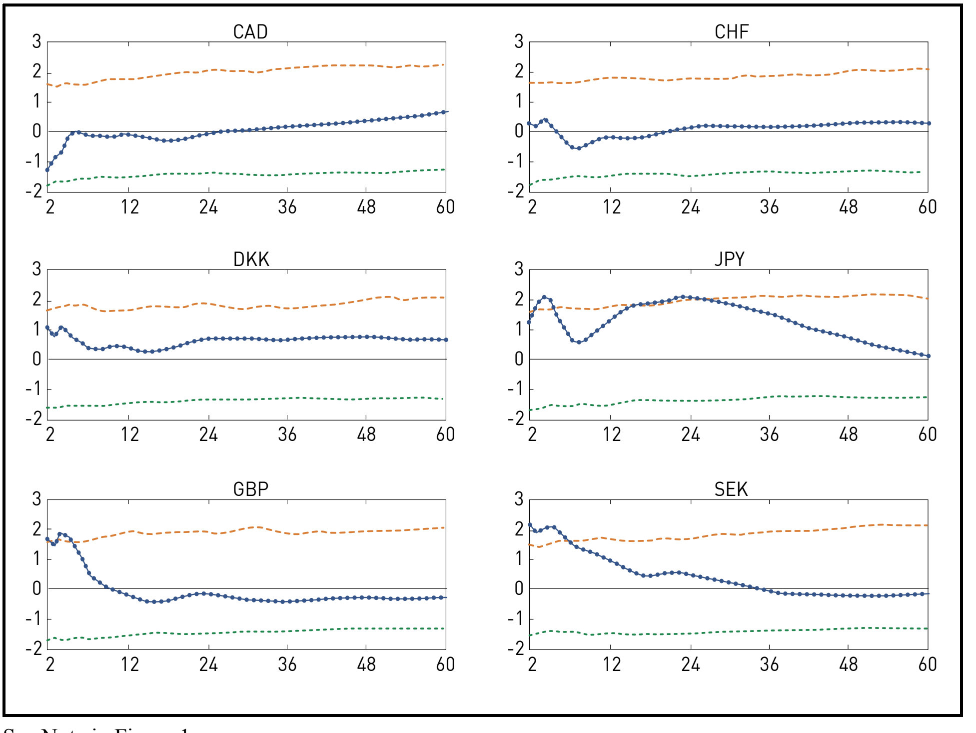
Figure 3. Continued



See Note in Figure 1.

We have shown that foreign exchange excess returns against the US dollar exhibit strong positive serial dependence patterns during the Volcker era and tend to be not predictable during the post-Volcker era. Further, we argue that their positive autocorrelations are consistent with the expectational errors hypothesis based on Kim, Moon, and Velasco (2017)'s explanation. We now conduct two more analyses in order to check robustness of our results. First, we investigate if the unpredictability of foreign exchange excess returns against the US dollar during the post-Volcker era is due to the credibility of the fed's monetary policy or the influence of international capital market integration. Second, we examine the influence of another US monetary policy regime change around the global financial crisis on the predictability of foreign exchange excess returns.

Figure 4. Patterns of t-statistics of the Estimated Variance Ratios for One-month Excess Returns for the Non-EMU Currencies Against the US Dollar During the Post-Volcker Era (1990-2015)

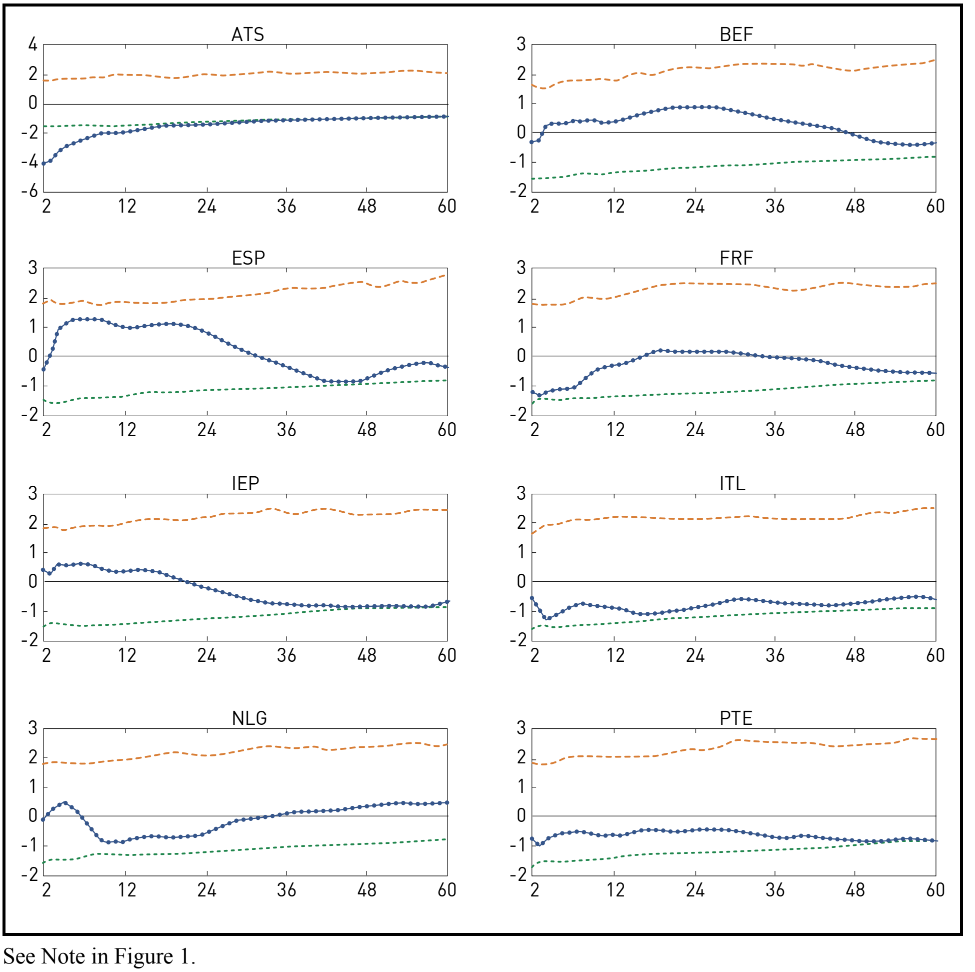


See Note in Figure 1.

We begin with the first case. UIP implies that foreign exchange excess returns are not predictable under the assumptions of rational expectations and risk neutrality. The implicit assumption underlies this hypothesis is that capital markets are efficient. Therefore, one may argue that the different results on the predictability of foreign exchange excess returns between the Volcker era and the post-Volcker era may be due to the development of international capital markets since the 1990s.

To investigate this possibility, we control for the influence of the fed's monetary policy on USD bilateral exchange rates. A simple method to do this is to eliminate the influence of common components in USD bilateral rates. That is we replace the USD with the GDM as a base currency using triangular arbitrage and assuming the absence of transaction costs. We then apply the same variance ratio test for the unpredictability of foreign exchange excess returns against the German mark. Finally, we compare the results of the serial dependence patterns of excess returns between the two samples: one with the USD as a base currency and the other with the GDM as a base currency.

Figure 5. Patterns of t-statistics of the Estimated Variance Ratios for One-month Excess Returns for the EMU Member Currencies Against the German Mark During the Volcker Era (1980-87)



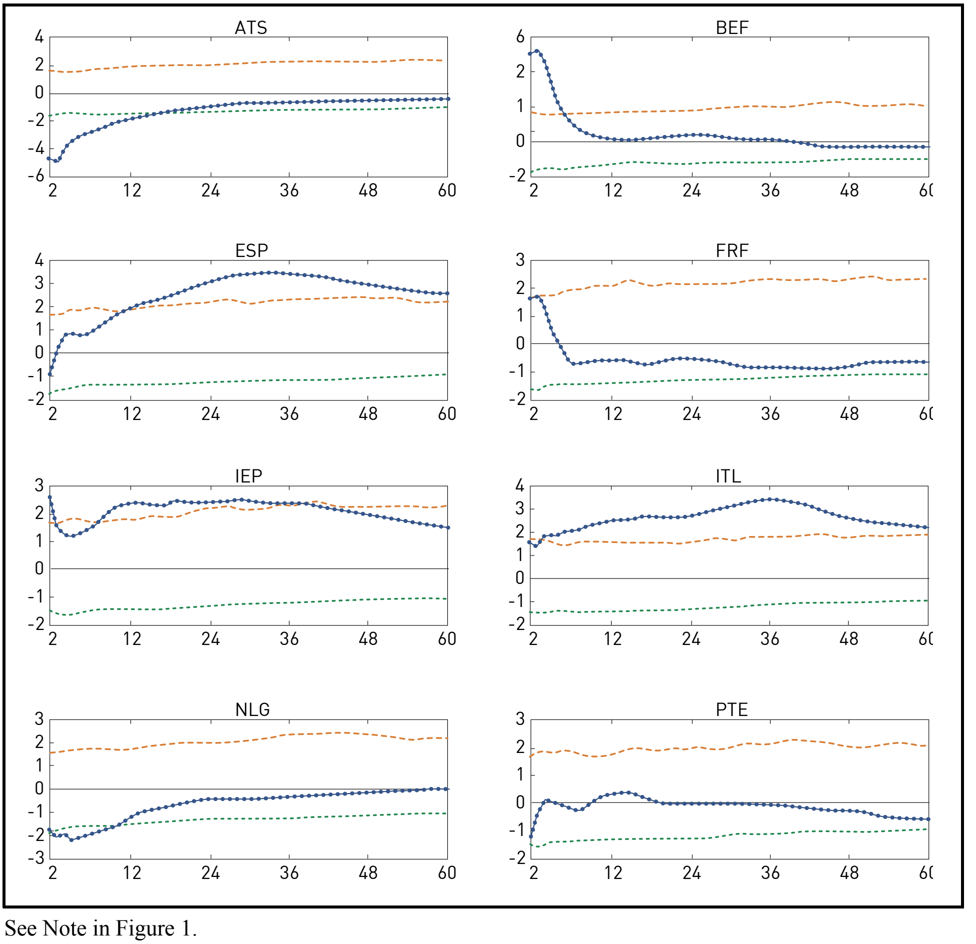
See Note in Figure 1.

Figures 5-6 present the results regarding the serial dependence patterns of foreign exchange excess returns against the German mark for the currencies of the EMU member countries. Overall, we find that the serial dependence patterns of foreign exchange excess returns against the German mark are quite different from those of excess returns against the US dollar. Specifically, as displayed in Figure 5, the t-statistics of estimated variance ratios are inside the band with the critical values of 5% and 95% over all return horizons q for the currencies of the EMU member countries except for ATS during the Volcker era, suggesting that those excess returns are not predictable. These results are quite different from those obtained using foreign exchange excess returns against the US dollar. Recall that those excess returns against the US dollar exhibit very strong positive serial dependence during the Volcker era. This difference between the two samples illustrates that the fed's contractionary monetary policy during the Volcker era very strongly affects the behavior of US bilateral exchange rates.

On the other hand, during the post-Volcker era the serial dependence patterns of foreign exchange excess returns against the German mark are quite diverse across the currencies of the EMU member countries as displayed in Figure 6. For example, foreign exchange excess returns for BEF, IEP, ITL, and ESP exhibit positive serial dependence patterns, while excess returns for ATL and NLG exhibit negative serial dependence patterns. And excess returns for FRF and PTE appear not to be predictable. Again these results are quite different from those obtained using excess returns against the US dollar. The different results regarding the predictability of excess returns between the sample with USD bilateral exchange rates and the sample with GDM bilateral rates confirm that the US fed's monetary policy regime significantly affect the behavior of foreign excess returns against the US dollar. Further, both the evidence on the unpredictability of foreign excess returns against the German mark during the Volcker era and the mixed evidence on the predictability of those excess returns during the post-Volcker era imply that the development of international capital markets is not likely derive the different results between the Volcker era and the post-Volcker era.

We now conduct the second robustness analysis. The US economy experienced a severe financial crisis and was in a deep recession between 2007 and 2009. In the face of this so called global financial crisis, the fed lowered its target interest rate close to zero. In addition, the fed took unprecedented steps to lower its target rate even further. One of these steps is to conduct quantitative easing policy buying a huge amount of US government bonds and mortgage-backed securities. These abnormal policies by the fed since 2017 may induce a change in US monetary policy regime. We investigate how these abnormal monetary policies affect the behavior of US bilateral exchange rates. For this, we divide the post-Volcker era into two subsample period: one sample period is between 1988 and 2006 and the other sample period is between 2007 and 2015. In particular, we investigate the serial dependence pattern of foreign exchange excess returns against the US dollar in the second subsample period.

Figure 6. Patterns of t-statistics of the Estimated Variance Ratios for One-month Excess Returns for the EMU Member Currencies Against the German Mark During the Post-Volcker Era (1988-98)



See Note in Figure 1.

Figures 7 presents the results regarding the serial dependence patterns of foreign exchange excess returns against the US dollar for the currencies of the non-EMU member countries for the sample period of 2007-2015. Overall, we find that the predictability of those excess returns is weak, similar to the results for the post-Volcker era between 1988 and 2015. However, the serial dependence patterns of excess returns for JPY, GBP, and SEK are different between the two sample periods. Specifically, the t-statistics of the estimated variance ratios are inside the band with the critical values of 5% and 95% over all return horizons q for CAD, CHF, and SEK, suggesting that we are not able to reject the null hypothesis of no predictability of excess returns. However, the t-statistics of the estimated variance ratios are positive and statistically significant over return horizons beyond one and half year for JPY and over return horizons within a year for GBP. In sum, we conclude that the US monetary policy regime change around the global financial crisis does not much affect the predictability of foreign exchange excess returns against the US dollar, suggesting that not all monetary policy regime change matters for the predictability of foreign exchange excess returns. On the other hand, these results support Kim, Moon, and Velasco (2017)'s argument that monetary policy regime change based on the imperfect credibility of monetary affects the predictability of foreign exchange excess returns.

Figure 7. Patterns of t-statistics of the Estimated Variance Ratios for One-month Excess Returns for the Non-EMU Member Currencies Against the US Dollar During the Post-Volcker Era (2007-2015)

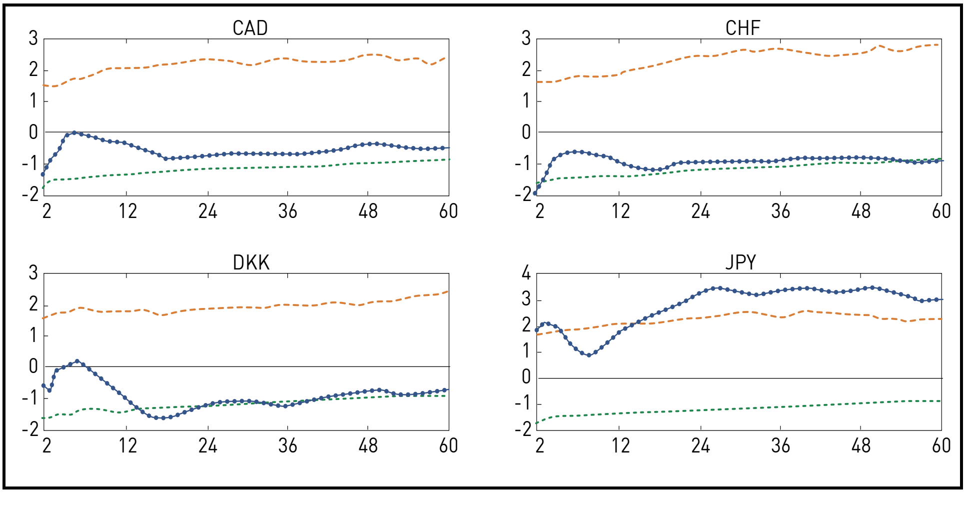
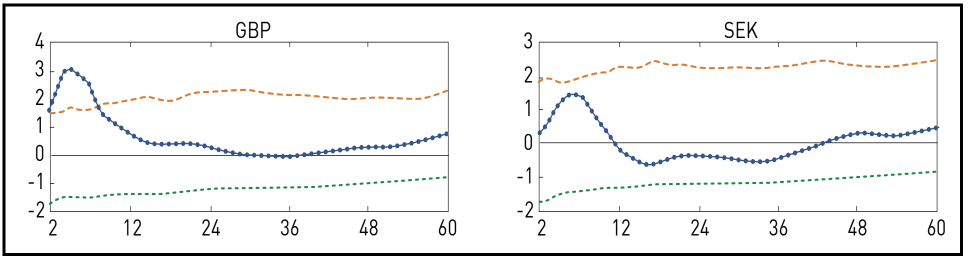


Figure 7. Continued



See Note in Figure 1.

V. CONCLUDING REMARKS

This paper proposes a simple identification scheme for the two well-known explanations for the causes of the non-zero expected excess returns: rational expectations risk premium and expectational errors. We first show that a mean reverting component in foreign exchange excess returns, representing a violation of UIP, can generate different serial dependence patterns of foreign exchange excess returns: economic models for the rational expectations risk premium tend to generate negative serial dependence patterns of foreign exchange excess returns, while economic models for the expectational errors tend to generate positive serial dependence patterns of excess returns. We then use the serial dependence patterns of excess returns observed in data as a criterion for judging the performance of economic models for the non-zero expected excess return which reflects a violation of UIP.

Using foreign exchange rates data for developed economies, we find that foreign exchange excess returns against the US dollar exhibit strong positive serial dependence patterns over return horizons between 2 and 60 months during the Volcker era, while they tend to be unpredictable during the post-Volcker era. The positive serial dependence patterns during the Volcker era is against the rational expectations risk premium hypothesis but consistent with the expectational errors explanation for the violations of UIP.

Admittedly, evidence on the positive serial dependence pattern during the Volcker era is not enough to conclude that violations of UIP is due to expectational errors. Nevertheless, we conducted additional exercises to make our argument more persuasive. First, we test an alternative hypothesis for the different results on the predictability of excess returns against the US dollar between the Volcker era and the post-Volcker era: the development of international capital market may derive the difference between the two sample periods. For this, we eliminate the influence of the US fed's monetary policy by replacing the USD with GDM as a base currency and find that foreign exchange excess returns against the GDM tend to be unpredictable for almost all currencies during the Volcker era, while serial dependence patterns of those excess returns are different across currencies during the post-Volcker era, suggesting that development of international capital market cannot be a main cause for the different results between the Volcker era and the post-Volcker era. Second, we consider the influence of another US monetary policy regime change around the global financial crisis but find that this monetary policy regime change does not much affect the predictability of excess returns against the USD, supporting Kim, Moon, and Velasco (2017)'s expectational error explanation based on the imperfect credibility of Volcker fed's disinflation policy during the early 1980s and the credibility of fed's monetary policy during the post-Volcker era.

TECHNICAL APPENDIX

In this section, we calculate the autocorrelation functions of excess returns from two rational expectations risk premium models: a monetary general equilibrium model with an endogenous source of risk variation by Alvarez, Atkeson, and Kehoe (2009) and an external habit persistence model by Verdelhan (2010). We also calculate the autocorrelation functions of excess returns from the expectational error model by Gourinchas and Tornell (2004). For conserving the space, we present only relevant ingredients of their models and refer to their papers for the details. We change some notations from their models to accommodate ours in the paper, while following the other notations from their models as much as possible.

1. A monetary general equilibrium model by Alvarez, Atkeson, and Kehoe(AAK)

Alvarez, Atkeson, and Kehoe (AAK) build a general equilibrium monetary model with segmented asset markets that generates time-varying risk premia. Specifically, it is a two-country cash-in-advance economy where there is an asset market available to both countries and one goods market in each country. The only source of uncertainty in this economy is shocks to money growth in the two countries. The key feature of the model is that each household must pay a fixed cost for each transfer of cash between the asset market and a goods market, and this fixed cost varies across households. So, in equilibrium, households with a sufficiently low fixed cost pay it and transfer cash between the asset and goods markets, while others do not. This segmentation of asset markets induces changes in money growth rates to have a real impact on consumption and thus the marginal utility of households who participate in this transfer.

The log of the home pricing kernel from AAK [equation (33)] is

$$\ln m_{t+1} = \ln \beta/\bar{\mu} - (1+\emptyset_1)\hat{\mu}_{t+1} + 0.5\emptyset_2(\hat{\mu}_{t+1})^2 + \emptyset_1\hat{\mu}_t - 0.5\emptyset_2(\hat{\mu}_t)^2 \tag{A.1}$$

where $\hat{\mu}_t = \ln \mu_t - \ln \bar{\mu}$ is the log deviation of the money growth rate, $\emptyset_1 \equiv -\frac{d \ln U'(C_A(\mu))}{d \ln \mu}|_{\mu=\bar{\mu}}$ is the elasticity of the marginal utility of active households' consumption to a change in money growth rate, which is evaluated at the steady state constant money growth rate $\bar{\mu}$, $\emptyset_2 \equiv \frac{d^2 \ln U'(C_A(\mu))}{(d \ln \mu)^2}|_{\mu=\bar{\mu}}$, and $U'(C_A(\mu))$ denotes the marginal utility of active households' consumption. AAK assume that the log deviation of money growth rate follows

$$\hat{\mu}_{t+1} = E_t[\hat{\mu}_{t+1}] + \eta_{t+1}, \tag{A.2}$$

where η_{t+1} is a normal random variable with mean zero and variance σ_η^2.

The risk premium from AAK [Proposition 4, equation (37)] is

$$p_t = E_t[s_{t+1}] - f_t = 0.5 \frac{1}{1 - \emptyset_2 \sigma_\eta^2} (Var_t[\ln m_{t+1}] - Var_t[\ln m_{t+1}^*]), \tag{A.3}$$

where $Var_t[\ln m_{t+1}] = (-(1 + \emptyset_1) + \emptyset_2 E_t[\hat{\mu}_{t+1}])^2 \sigma_\eta^2 + \frac{3}{4} \emptyset_2^2 \sigma_\eta^4$ and a symmetric formula holds for $Var_t[\ln m_{t+1}^*]$. In this model, the persistence of the risk premium depends on that of the money growth rate. For example, if the money growth rate is i.i.d. then the risk premium becomes constant. From equations (6), (7), and (A.1) (and the foreign counterpart), the forecasting error can be derived as

$$\begin{aligned} fd_{t+1} + fp_{t+1} &= (\ln m_{t+1}^* - E_t[\ln m_{t+1}^*]) - (\ln m_{t+1} - E_t[\ln m_{t+1}]) \\ &= (-(1 + \emptyset_1) + \emptyset_2 E_t[\hat{\mu}_{t+1}^*]) \eta_{t+1}^* + 0.5 \emptyset_2 (\eta_{t+1}^*)^2 \\ &\quad -(-(1 + \emptyset_1) + \emptyset_2 E_t[\hat{\mu}_{t+1}]) \eta_{t+1} - 0.5 \emptyset_2 (\eta_{t+1})^2 \end{aligned} \tag{A.4}$$

To investigate the sign of the autocorrelation of foreign exchange excess return, we assume $\eta_{t+1}^* = 0$ without loss of generality. Then, using equations (A.3)-(A.4), the first order autocovariance of foreign excess returns is derived as

$$\begin{aligned} \mathrm{Cov}(r_{t+1}^e, r_{t+2}^e) &= Cov\Big(-(-(1 + \emptyset_1) + \emptyset_2 E_t[\hat{\mu}_{t+1}]) \eta_{t+1} - 0.5 \emptyset_2 (\eta_{t+1})^2 \\ &\quad + p_t, p_{t+1}\Big) \\ &= Cov\Big(-(-(1 + \emptyset_1) + \emptyset_2 E_t[\hat{\mu}_{t+1}]) \eta_{t+1} \\ &\quad - 0.5 \emptyset_2 (\eta_{t+1})^2, \varepsilon_{t+1}\Big) + Cov(p_t, E_t[p_{t+1}]) \end{aligned}$$

where $\varepsilon_{t+1} = p_{t+1} - E_t[p_{t+1}]$. Under $E_t[\hat{\mu}_{t+1}] = \rho\hat{\mu}_t$ and the parameter values of $\emptyset_2 = 1000$, ρ =0.9, and $\sigma_\eta = 0.0035$ set by AAK, the sign of $\text{Cov}(r^e_{t+1}, r^e_{t+2})$ is negative.[11]

Proof: From equation (A.3) and using $E_t[\hat{\mu}_{t+1}] = \rho\hat{\mu}_t$, we derive

$$\varepsilon_{t+1} = 0.5\frac{\rho\emptyset_2\sigma_\eta^2}{1-\emptyset_2\sigma_\eta^2}(-2(1+\emptyset_1-\emptyset_2\rho^2\hat{\mu}_t)\eta_{t+1}+\emptyset_2\rho\eta_{t+1}^2).$$

Then, $\text{Cov}\left(\left((1+\emptyset_1)-\emptyset_2 E_t[\hat{\mu}_{t+1}]\right)\eta_{t+1}-0.5\emptyset_2\rho\eta_{t+1}^2, \varepsilon_{t+1}\right)$

$= -\frac{\rho\emptyset_2\sigma_\eta^2}{1-\emptyset_2\sigma_\eta^2}\left((1+\emptyset_1)^2\sigma_\eta^2+\emptyset_2^2\rho\left(\left(\frac{\rho^3}{1-\rho^2}\right)+\frac{3}{4}\right)\sigma_\eta^4\right)$ And $Cov(p_t, E_t[p_{t+1}])$

$= \frac{\rho\emptyset_2\sigma_\eta^2}{1-\emptyset_2\sigma_\eta^2}((1+\emptyset_1)^2\ \left(\frac{\rho}{1-\rho^2}\right)\sigma_\eta^2+\emptyset_2^2\frac{\rho^4}{2(1-\rho^2)^2}\sigma_\eta^4)$. To calculate the two covariances, we use the results that $E_t[\eta_{t+1}^4] = 3\sigma_\eta^4$, $E_t[\eta_{t+1}^3] = 0$, $E[\hat{\mu}_t] = 0$, $E[\hat{\mu}_t^2] = \frac{\sigma_\eta^2}{1-\rho^2}$, $E[\hat{\mu}_t^3] = 0$, and $E[\hat{\mu}_t^4] = \frac{3\rho^4}{(1-\rho^2)^2}$. Now, the sum of the two covariances is

$$\text{Cov}(r^e_{t+1}, r^e_{t+2}) = -\frac{\rho\emptyset_2\sigma_\eta^2}{1-\emptyset_2\sigma_\eta^2}\left((1+\emptyset_1)^2\sigma_\eta^2\left(1-\frac{\rho\emptyset_2\sigma_\eta^2}{1-\emptyset_2\sigma_\eta^2}\left(\frac{\rho}{1-\rho^2}\right)\right)\right) - \frac{\rho\emptyset_2\sigma_\eta^2}{1-\emptyset_2\sigma_\eta^2}\frac{\emptyset_2^2\rho^4\sigma_\eta^4}{1-\rho^2}(1+\frac{3(1-\rho^2)}{4\rho^3}-\frac{\rho\emptyset_2\sigma_\eta^2}{1-\emptyset_2\sigma_\eta^2}\frac{1}{2(1-\rho^2)^2}). \quad \text{(A.5)}$$

As can be seen in the above equation, the sign of the autocovariance depends on the three parameter values, $\emptyset_2$, ρ, and σ_η. And one can easily see that the sign of autocovariance is negative with the parameter values specified above.

2. An external habit persistence model by Verdelhan

Verdelhan builds a model which focuses on real risk, abstracting from money and inflation. Specifically, it is a two country endowment economy with complete asset

[11] AKK consider that $E_t[\hat{\mu}_{t+1}]$ is a quadratic function in $\hat{\mu}_t$. They also show that the resulting money growth process with the quadratic function is similar to that of an AR(1) process with ρ =0.9 . To get an analytical result, we assume the AR(1) process.

markets. The key feature of the model is that a representative household is characterized by external habit preference with time varying risk-free rates. The only source of uncertainty in this economy is shocks to consumption growth in the two countries.

The log of the home pricing kernel from Verdelhan [equation (1)] is

$$\ln m_{t+1} = \ln \beta - \gamma[\mathrm{g} + (\emptyset - 1)(z_t - \bar{z}) + (1 + \lambda(z_t))(\Delta c_{t+1} - g)] \tag{A.6}$$

where γ is the risk aversion parameter, z_t is the log of the surplus consumption ratio, and c_t is the log of consumption. He assumes that in both countries, idiosyncratic shocks to consumption growth are i.i.d. log-normally distributed

$$\Delta c_{t+1} = g + \eta_{t+1}, \tag{A.7}$$

where η_{t+1} is an i.i.d. normal random variable with mean zero and variance σ_η^2. He also assumes that

$$z_{t+1} = (1 - \emptyset)\bar{\mathrm{z}} + \emptyset z_t + \lambda(z_t)\eta_{t+1}, \tag{A.8}$$

Since money and inflation are abstracted in this model, the logs of home (foreign) stochastic discount factors are related to the change in the log of the real exchange

$$q_{t+1} - q_t = \ln m_{t+1}^* - \ln m_{t+1}, \tag{A.9}$$

and obviously the expected change in the real exchange rate is

$$E_t[q_{t+1}] - q_t = E_t[\ln m_{t+1}^*] - E_t[\ln m_{t+1}], \tag{A.10}$$

Accordingly, the foreign exchange excess return is defined by

$$r_{t+1}^e = q_{t+1} - q_t + r_t^* - r_t, \tag{A.11}$$

where home real interest rate is defined by

$$r_t = -E_t[\ln m_{t+1}] - 0.5Var_t[\ln m_{t+1}]], \tag{A.12}$$

and a symmetric holds for the foreign real interest rate r_t^*.

The risk premium from Verdelhan [equation (4)] is

$$p_t = E_t[\Delta q_{t+1}] + r_t^* - r_t = 0.5(Var_t[\ln m_{t+1}] - Var_t[\ln m_{t+1}^*]), \tag{A.13}$$

where $Var_t[\ln m_{t+1}] = \frac{\gamma^2\sigma_\eta^2}{\bar{z}}\big(1 - 2(z_t - \bar{z})\big)$ and a symmetric formula holds for $Var_t[\ln m_{t+1}^*]$. In this model, the persistence of the risk premium depends on that of z_t. From equations (A.6), (A.9), (A.10), (A.11), and (A.12) (and the foreign counterparts), the forecasting error can be derived

$$\begin{aligned} r_{t+1}^e - E_t[r_{t+1}^e] &= (\ln m_{t+1}^* - E_t[\ln m_{t+1}^*]) - (\ln m_{t+1} - E_t[\ln m_{t+1}]) \\ &= \gamma\big(1 + \lambda(z_t)\big)\eta_{t+1} - \gamma\big(1 + \lambda(z_t^*)\big)\eta_{t+1}^*, \end{aligned} \tag{A.14}$$

To investigate the sign of the autocorrelation of the (real) foreign excess return, again we assume $\eta_{t+1}^* = 0$ without loss of generality. Then, using equations (A.13) and (A.14), the first order autocovariance of foreign excess returns is derived as

$$\begin{aligned} \text{Cov}(r_{t+1}^e, r_{t+2}^e) &= \text{Cov}\big(\gamma\big(1 + \lambda(z_t)\big)\eta_{t+1} + p_t, p_{t+1}\big) \\ &= \text{Cov}\big(\gamma\big(1 + \lambda(z_t)\big)\eta_{t+1}, \varepsilon_{t+1}\big) + \text{Cov}(p_t, E_t[p_{t+1}]). \end{aligned} \tag{A.15}$$

where $\varepsilon_{t+1} = p_{t+1} - E_t[p_{t+1}]$. With the parameter values of $\gamma = 2$, $\emptyset = 0.995$, $\bar{z} = 0.07$, and $\sigma_\eta = 0.0051$ set by Verdelhan, the sign of $\text{Cov}(r_{t+1}^e, r_{t+2}^e)$ is negative.

Proof: From equations (A8) and (A13), we derive

$$\varepsilon_{t+1} = -\frac{\gamma^2\sigma_\eta^2}{\bar{z}}\lambda(z_t)\eta_{t+1}$$

Then, $\text{Cov}\big(\gamma\big(1 + \lambda(z_t)\big)\eta_{t+1}, \varepsilon_{t+1}\big) = -\frac{\gamma^3\sigma_\eta^2}{\bar{z}}E\big[\lambda(z_t)\big(1 + \lambda(z_t)\big)\big]\sigma_\eta^2$, and Cov $(p_t, E_t[p_{t+1}]) = (\frac{\gamma^2\sigma_\eta^2}{\bar{z}})^2\frac{\emptyset}{1-\emptyset^2}E[\lambda(z_t)\lambda(z_t)]\sigma_\eta^2$. The sum of the two covariances is

$$\mathrm{Cov}(r^e_{t+1}, r^e_{t+2}) = -\frac{\gamma^3\sigma_\eta^2}{\bar{z}}E[\lambda(z_t)\lambda(z_t)](1-\frac{\emptyset}{1-\emptyset^2}\frac{\gamma}{\bar{z}}\frac{\sigma_\eta^2}{\bar{z}}) - \frac{\gamma^3\sigma_\eta^2}{\bar{z}}E[\lambda(z_t)]\sigma_\eta^2, \quad \text{(A.16)}$$

Here, we only focus on the first term in the left-hand of equation (A.16) since the sign of the second term is negative. The sign of the first term depends on the four parameter values, γ, $\emptyset$, $\bar{z}$, and σ_η. And one can easily see that the sign of the autocovariance is negative with the parameter values above.

3. An expectational error model by Gourinchas and Tornell (GT)

Gourinchas and Tornell (GT) build an expectational error model where agents systematically make errors in perceiving interest rate innovations. GT assume complete markets for nominal assets. The key feature of the model is that agents forecast the future interest rate differences between home and foreign countries using Bayes rules given their beliefs, after observing the current interest rate difference which is exogenously given. There are two sources of uncertainty in this economy: one is a shock to the interest rate difference between the two countries and the other is a shock to the degree on the belief of the relative importance of transitory component in the interest rate difference process.

We begin with rewriting the definition of the violations of UIP in equation (2) in the main text:

$$E_t[\Delta s_{t+1}] - (i_t - i_t^*) = d_t,$$

where d_t represents the rational expectations risk premium, expectational errors, or both. GT assume that the risk premium is zero and the subjective expectation (the market expectation) is different from the rational (statistical) expectation and define 'subjective UIP' in the following way:

$$E_t^s[\Delta s_{t+1}] = x_t \quad \text{(A.17)}$$

where $E_t^s[\cdot]$ is the subjective expectation (the market expectation) and $x_t = i_t - i_t^*$. Expectational errors are the difference between the subjective expectation and the rational expectation. GT take the interest rate difference between two countries (the forward premium) as given and assume that x_t follows an AR(1) process (GT, equation (4)):

$$x_t = \lambda x_{t-1} + \epsilon_t, \tag{A.18}$$

where ϵ_t is normally distributed with mean zero and variance σ_ϵ^2. While equation (A.18) characterizes the true process for the interest rate difference, agents have the following beliefs about the process for the interest rate difference:

$$x_t = z_t + \nu_t,\ z_t = \lambda z_{t-1} + \epsilon_t, \tag{A.19}$$

where υ_t follows an i.i.d. normal distribution with mean zero and variance σ_υ^2 and measures how much agents' perceive the actual interest shock as more transitory than it actually is. Given their beliefs, agents forecast future forward premium using Bayes rules after they observe the realization of x_t every period:

$$E_t^s x_{t+1} = (1-k_t)\lambda E_{t-1}^s x_t + k_t \lambda x_t, \tag{A.20}$$

where $\sigma_{t+1}^2 = (1-k_t)(\lambda^2\sigma_t^2 + \sigma_\epsilon^2),\ 0 \le k_t = \frac{\lambda^2\sigma_t^2+\sigma_\epsilon^2}{\lambda^2\sigma_t^2+\sigma_\epsilon^2+\sigma_\upsilon^{s2}} \le 1$. In the limit as $t \to \infty$, the conditional variance σ_{t+1}^2 and k_t converge to steady state values σ^2 and k, respectively, that satisfy:

$$\sigma^2 = \frac{1-k}{1-(1-k)\lambda^2}\sigma_\epsilon^2, \tag{A.21}$$

And the beliefs evolves accordingly

$$E_t^s x_{t+1} = (1-k)\lambda E_{t-1}^s x_t + k\lambda x_t, \tag{A.22}$$

Then, the equilibrium exchange rate is determined by solving equation (A.17):

$$s_t = \bar{s}_t - x_t - \frac{1}{1-\lambda} E_t^s x_{t+1}, \tag{A.23}$$

where $\overline{s}_t$ is the long-run equilibrium exchange rate. Finally, the foreign exchange excess return is defined by

$$r_{t+1}^{e} = s_{t+1} - s_{t} - x_{t} = \phi_0(E_t^s x_{t+1} - x_{t+1}) = \phi_0(E_t^s x_{t+1} - E_t x_{t+1} - \epsilon_{t+1}), \tag{A.24}$$

where $\overline{s}_t$ is assumed to be zero and $\phi_0 = \frac{1-\lambda(1-k)}{1-k}$. Equation (24) shows that foreign exchange excess returns can be decomposed into two parts: forecasting errors, $-\phi_0\epsilon_{t+1}$, and expectational errors, $\phi_0(E_t^s x_{t+1} - E_t x_{t+1})$.

To investigate the sign of the autocorrelation of the (real) foreign excess return, we derive the first order autocovariance of foreign exchange excess returns as

$$\begin{aligned} \text{Cov}(r_{t+1}^{e}, r_{t+2}^{e}) &= \phi_0^2 \text{Cov}(E_t^s x_{t+1} - x_{t+1}, E_{t+1}^s x_{t+2} - x_{t+2}) \\ &= \phi_0^2 \text{Cov}(E_t^s x_{t+1} - x_{t+1}, (1-k)\lambda E_t^s x_{t+1} + k\lambda x_{t+1} - x_{t+2}). \end{aligned} \tag{A.25}$$

For $0 < \lambda < 1$ and $0 < k < 1$, the sign of $\text{Cov}(r_{t+1}^{e}, r_{t+2}^{e})$ is positive.

Proof: Rearrange equation (A.25), we have

$$\begin{aligned} \text{Cov}(r_{t+1}^{e}, r_{t+2}^{e}) = {} & \phi_0^2(1-k)\lambda Var(E_t^s x_{t+1}) - 2\phi_0^2\lambda^2(1-k)\text{Cov}(E_t^s x_{t+1}, x_t) \\ & + \phi_0^2(1-k)\lambda Var(x_{t+1}) \end{aligned}$$

Using $\text{Cov}(E_t^s x_{t+1}, x_t) = \frac{\lambda k}{1-\lambda^2(1-k)} Var(x_{t+1})$ and $Var(E_t^s x_{t+1}) = \frac{1}{1-\lambda^2(1-k)^2} [k^2\lambda^2 + \frac{2(1-k)k^2\lambda^4}{1-\lambda^2(1-k)}] Var(x_{t+1})$ [see GT(p. 332) for the derivation of these two terms], we have

$$\begin{aligned} \text{Cov}(r_{t+1}^{e}, r_{t+2}^{e}) = \phi_0^2(1-k)\lambda \Bigg[& \frac{1}{1-\lambda^2(1-k)^2}\left(k^2\lambda^2 + \frac{2(1-k)k^2\lambda^4}{1-\lambda^2(1-k)}\right) \\ & - 2\lambda \frac{\lambda k}{1-\lambda^2(1-k)} + 1 \Bigg] Var(x_{t+1}). \end{aligned}$$

Then, for $0 < \lambda < 1$ and $0 < k < 1$, one can easily show that $\text{Cov}(r_{t+1}^{e}, r_{t+2}^{e})$ is positive.

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First version received on 2 August 2018
Peer-reviewed version received on 20 September 2018
Final version accepted on 19 October 2018