Inflation Risk Premium and Foreign Exchange Rate

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Abstracts

Engel (2016) highlights puzzling patterns regarding interest rate differentials and foreign exchange rates: while a high-interest-rate currency tends to earn a positive excess return in the short run, its long-run excess return tends to be negative. We present an explanation of these patterns based on inflation risk premium: whereas short-term interest rates do not affect short-term inflation risk premia (because of price stickiness),,they negatively affect long-term inflation risk premia (because of money neutrality). Different responses of short-term and long-term inflation risk premia generate different patterns of short-term and long-term FX excess returns. We present empirical evidence to support this explanation.

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1. Introduction

Engel (2016) highlights puzzling patterns regarding interest rate differentials and foreign exchange rates. When the interest rate of country A is higher than that of country B, currency A earns positive excess returns in the short run (let us call this "the short-run pattern"); at the same time, currency A earns negative excess returns in the long run ("the long-run pattern"). Engel argues that these two patterns together cannot be explained by existing theories. Models of foreign exchange (FX) risk premium may explain the short-run pattern, but not the long-run pattern. Models of overshooting may explain the long-run pattern, but not the short-run pattern. Hence, these two patterns together remain a puzzle.

We seek an explanation for this puzzle by focusing on inflation risk premium. Inflation risk premium has not received its due attention in the FX literature so far; our research aims to fill this gap in the literature.

Our explanation is based on three observations: (i) Inflation risk premium differential is a component of FX risk premium. (ii) Long-term inflation risk premium responds negatively to interest rate movement, generating the long-run pattern of the FX excess returns. (iii) Short-term inflation risk premium does not respond to interest rate movement, thus allowing the other components of FX risk premium to generate the short-run pattern of the FX excess returns.

We derive (i) from the definition of inflation risk premium and the international version of the Fisher equation. We can also understand this more intuitively. Inflation risk premium is what bond market participants demand as compensation for being exposed to inflation risk (i.e., for holding assets that are affected by unexpected changes in inflation). FX market participants are exposed to inflation risk in the same way as bond market participants, thus they demand a similar compensation for this exposure. Therefore, inflation risk premium is a part of FX risk premium. For example, a 1% increase in inflation risk premium results in a 1% increase in FX risk premium.

We motivate (ii) and (iii) from the phenomenon of price stickiness. Suppose that the foreign central bank tightens monetary policy.[1] The following would happen in the foreign country: short-term nominal interest rates would go up (high i_S^*). Short-term inflation expectation would not be affected—due to price stickiness—and, thus, short-term *real* rate would rise instead (high r_S^*). On the other

[1] We motivate our idea by assuming that the changes in short rate mostly reflect the changes in monetary policy. In reality, the short rate is influenced by many other factors.

hand, price is not sticky in the long term, so people would expect inflation rates to become lower eventually, after some delay. Thus, long-term inflation expectation would become lower, which in turn would lead to lower long-term inflation risk premium (low irp_L^*).[2] In the FX market, the following would happen: a higher short-term real rate in the foreign country would lead to positive short-term FX excess return, ρ_S (high r_S^* → positive ρ_S). This would be due to a positive correlation between real rate differential and FX risk premium, which is a well-established fact in the FX risk premium literature (e.g. Bilson (1981), Fama (1984), and Engel (2014)). Lower long-term inflation risk premium in the foreign country leads to negative long-term FX excess return, ρ_L (low irp_L^* → negative ρ_L). This follows from the fact that inflation risk premium differential is a component of FX risk premium. Thus, we obtain both positive FX excess returns in the short-run and negative FX excess returns in the long-run.

To better understand the role of inflation risk premium in the previous scenario, it may help to rephrase our explanation without explicit reference to inflation risk premium. Suppose again that the foreign central bank tightens monetary policy. In the foreign country, short-tern nominal interest rate would rise (high i_S^*), but long-term nominal interest rates would either show no change or decline (low i_L^*). FX excess returns have the same signs as interest rate differentials. Thus, we would observe positive FX excess returns in the short run (high i_S^* → positive ρ_S) and negative FX excess returns in the long run (low i_L^* → negative ρ_L). However, it is unclear why the long-term nominal interest rate moves in the opposite direction to the short-term nominal interest rate. It is also unclear why FX excess returns have the same sign as interest rate differentials. Inflation risk premium helps us address these questions coherently. Our explanation of why the long-term nominal interest rate moves in the opposite direction to the short-term nominal interest rate rests on the recognition that people form expectations related to inflation in the short-term and long-term differently. Thus, the inflation expectation component of the long-term rate move in response to moneytary policy whereas the inflation expectation component of the short-term rate does not. This pattern is consistent by the findings of Evans and Marshall (1998), Drakos (2001), and Berument and Froyen (2006) that the long-term nominal rate responds less to monetary policy than the short-term nominal rate. Our explanation of why FX excess returns have the same sign as interest rate differentials is based on the recognition that inflation risk premium is one of two components of FX risk premium (the other component being real FX risk premium).

In earlier literature, Frankel (1979) emphasized that long-term interest rates may move differently from short-term interest rates and that this has direct implications for the term structure of FX

[2] Kliesen and Schmid (2004) report that monetary policy shock affects the quantity of inflation risk.

returns. Our innovation relative to Frankel (1979) is to clarify the interaction of relevant variables via the concept of inflation risk premium. While our explanation is presented using the framework of risk premium, our prediction for FX rate movement is mostly in line with Frankel's (1979) and Dornbusch's (1976) predictions based on the overshooting model.

We confirm the main implications of our explanations empirically using data on the USD-GBP currency pair, for which reliable data from indexed bond markets exist. Given the difficulty of measuring long-run expected returns, we follow Engel's (2016) Vector Error Correction Model (VECM) approach to estimate the expected value of long-term FX excess returns. We repeat some of the analyses using data on other currency pairs for which we have more limited time-series availability.

We are mindful of the possible effects of the term premium and the liquidity premium. We note, however, that the term premium is unlikely to be a main driver of the long-term FX excess return (ρ_L). To generate the desired movement in ρ_L, the term premium contained in the foreign long-term real rate (r_L^*) has to correlate negatively with the foreign short rate (i_s^*). Such negative correlation is highly unlikely. Most likely, there is little to no correlation between i_s^* and r_L^*. Liquidity premium is a bigger challenge as it may affect the measurement of our key variables. To control for the effect of the liquidity premium, especially in the measurement of the inflation risk premium, we plan to adopt an empirical strategy that explicitly account for the liquidity premium.

The remainder of this paper is organized as follows. In Section 2, we review related literature. In Section 3, we introduce the hypotheses to be tested and motivate them using a decomposition of the FX risk premium. Section 4 presents empirical evidence from the USD-GBP pair. Section 5 presents empirical evidence from other currency pairs. Section 6 discuss the next steps that we plan to take.

2. Related Literature

We start this section by reviewing Engel's (2016) findings and discussing related research. We then comment on the overshooting models of Dornbusch (1976) and Frankel (1979). Finally, we discuss our potential contribution to other related literature.

A. Engel (2016) and Related Literature

The foreign exchange rate puzzle highlighted by Engel (2016) can be restated as follows: there are two strands of literature dealing with foreign exchange rate. The first is the finance view of foreign exchange rate (Bilson, 1981; Fama, 1984; Engel 2014), and it emphasizes the deviation from the interest rate parity, i.e., the existence of carry profit. When a country has a higher interest rate, the interest rate parity requires that its currency depreciate over time. In reality, such currency tends to depreciate, but not as much as required by the interest rate parity. Thus, relative to interest rate parity, high-interest currency is under-valued.

The second strand of literature is the economic view of foreign exchange rate, and it emphasizes the deviation from the purchasing power parity (Rogoff, 1996; Taylor and Taylor, 2004). One of the stylized facts in this literature is the overshooting of the FX rate. The standard models of overshooting (e.g., Dornbusch, 1976) predict (and such prediction has been confirmed empirically) that, when a country has a higher interest rate, its currency becomes over-valued relative to the equilibrium PPP-consistent level. This is essentially the same phenomenon as the excess volatility emphasized by Rogoff (1996). The FX rate exhibits excess volatility as it often overshoots above the equilibrium level. Without overshooting, the volatility would have been smaller than the volatility of the equilibrium level.

Thus, the finance view and the economic view say the opposite things: the currency of a high-interest country is under-valued in one measure and over-valued in another measure. That the exchange rate seems under-valued and over-valued at the same time is not a puzzle in its own right. We have a puzzle only because the existing theories and models cannot explain two views simultaneously.

The finance view explains the under-valuation via FX risk premium. If the FX risk premium for a high-interest currency is positive, then the value of the currency should be lower than interest-rate-parity level, to reward investors for taking extra risk. This line of thinking cannot explain over-valuation relative to long-run equilibrium level.

The economic view explains the over-valuation via sticky prices. When there is monetary tightening, price level does not adjust due to sticky prices, and the real interest rate goes up. The higher real interest rate pushes up the real value of the currency more than the equilibrium level since the current real interest rate is higher than the equilibrium real interest rate. (The equilibrium real interest rate is lower since the real interest rate will eventually come down.) This line of thinking cannot explain the under-valuation in the short-run.

In our research, we start from the finance view, and introduce price stickiness and inflation risk premium. Then, the under-adjustment of FX rates to short rate changes is the result of the real-exchange-rate risk premium; at the same time, the over-adjustment occurs as a result of the expectation of the delayed response of inflation rate.

Let us take the finance view of the FX rate, and note the fact that the FX risk premium has two components: (1) real FX risk premium and (2) inflation risk premium. If a country has a higher interest rate, and if a higher interest rate is associated with higher FX risk (as is typically assumed), then the value of the currency should be lower than the interest-rate-parity level, to reward investors for taking FX risk. This is what the standard finance view says. Note that we can replace "interest rate" with "real interest rate," and also "FX risk" with "real FX risk" since short-term nominal interest rate is likely to be close to real interest rate. For example, monetary shocks may not affect short-term inflation expectation, making short-term nominal interest rate identical to real interest rate.

Then how about long-run inflation expectation? Monetary shocks will affect long-run inflation expectation; investors will believe that inflation rate will be affected at some point in the future. If the monetary shock is in the form of tightening, then investors will expect lower inflation rate in the future, and inflation risk premium may be negative. This will be translated into negative expected FX return for some future periods. Such negative expected return is consistent with the over-valuation relative to the long-run equilibrium level.

Engel (2016) emphasized a possible role of liquidity premium behind the puzzle. Inflation risk premium emphasized in our research is conceptually distinct from the liquidity premium. Inflation risk premium is what investors demand as a compensation for being exposed to inflation; the size of the premium is independent from the liquidity of a particular instrument that people choose to trade. In empirical works, however, the liquidity premium may be included in the measurement of inflation risk premium. For example, it has been noted by many authors (e.g., Gurkaynak, Sack, Wright, 2008) that the yield on inflation protected bonds includes an illiquidity premium, which is difficult to measure and separate from the estimate of the inflation risk premium.

B. More on Overshooting Model

Frankel (1979) emphasized the fact that, under short-run price stickiness, the short rate and the long rate may move in the opposite direction, making the correlation between the exchange rate and the interest rate look very different depending on whether we look at the short rate or the long rate. For example, when the central bank adopts expansionary monetary policy, the short rate becomes lower due to short-term price stickiness (i.e., no immediate inflation) whereas the long rate becomes higher reflecting long-term price neutrality (i.e., higher inflation expectation). The value of the currency initially drops and gradually goes up toward the long-term equilibrium level. Thus, the correlation between the currency return (positive) and the short rate (low) is negative, whereas the correlation between the currency return (positive) and the long rate (high) is positive.

We develop this idea further, incorporating what we know about the deviation from the uncovered interest rate parity (UIP): since the short rate is low, the currency earns negative excess returns relative to the short rate. Since the long rate is high, the currency earns positive excess returns relative to the long rate. Thus, relative to the short rate, the currency is over-valued. Relative to the long rate, the currency is under-valued.

The FX rate movement that we are thinking of can be consistent with the overshooting model. To understand the idea, suppose that the central bank increased money supply. Panel A in Figure 1 is consistent with Dornbusch (1976) and Frankel (1979). Now, suppose that the inflation is expected to be higher in the second period (and comes back to the initial level from the third period) and that the long rate (2-period rate) reflects this expectation. Then the long rate consistent path can be drawn as in Panel B in Figure 1. If the short rate goes down in the first period and goes up in the second period, then the short-rate consistent path can be added as in Panel C in Figure 1. Considering the typical deviation from the UIP path, the actual path may be as in Panel D in Figure 1. Note that the "UIP-deviation path" is not entirely inconsistent with Dornbusch (1976) and Frankel (1979). A part of their idea is that the exchange rate overshoot relative to the PPP equilibrium path. The UIP-deviation path is overshooting relative to the PPP equilibrium path as well. Also, Dornbusch (1976) and Frankel (1979) focus on "initial depreciation and subsequent gradual appreciation" which is what the "UIP-deviation path" is exhibiting. The "UIP-deviation path" is consistent with Engel's (2016) description of long-run exchange rate movement. Note, in particular, that the initial level is undervalued relative to the UIP (short) path, and over-valued relative to the long-run PPP equilibrium level.

C. Other Relevant Papers

Sarno, Schneider, and Wagner (2012), using a structural model of yield curve, showed that FX risk premium can explain the uncovered interest parity puzzle (i.e., the short-term pattern we described in 1). Our contribution is to identify components of FX risk premium and show that FX risk premium and, in particular, the inflation risk premium component drives the long-term pattern as well as short-term pattern.

Balduzzi and Chiang (2016) show that real exchange rate predicts FX excess return. Our research complements their paper by showing that inflation risk premium differential predicts many-year ahead FX excess returns. Our decomposition formula shows that inflation risk premium differential and the change in real exchange rate are components of FX excess returns; not accounting for inflation risk premium may attribute some of the predictability of inflation risk premium to real exchange rates.

Eichenbaum, Johannsen, and Rebelo (2017) focus on the following pattern: real exchange rate now is negatively correlated with nominal exchange rate in the future. The paper explains this pattern via real shock, e.g., productivity shock. A negative productivity shock in one country makes the real exchange rate of the second country lower. When inflation does not change in either countries, to restore the PPP, the currency of the second country should appreciate, resulting in the increase in the nominal exchange rate. This pattern is also consistent with our story. Our story is based on the monetary shock. Monetary expansion in the second country lowers short-term nominal interest rate, and the value of the currency declines. Given the short-term price stickiness, the short-term inflation does not change. Thus, the real exchange rate moves in the same direction as the nominal exchange rate. Therefore, the real exchange rate goes down. In the long term, money is neutral, and inflation rate goes up in the second country, and nominal interest rate goes up. The value of the currency increases and we observe an increase in the nominal exchange rate. Therefore, our paper complements Eichenbaum et al. (2017) in that we provide an alternative perspective to explain the empirical pattern.

3. Hypotheses and Some Theoretical Consideration

The main hypotheses of this paper can be stated in terms of covariances between pairs of variables. We motivate these hypotheses from a decomposition of FX risk premium.

A. Decomposition of FX Risk Premium

Let us start with the uncovered interest rate parity relation:

(1) $$i^{*} + \mathrm{E}(\log S_1/S_0) = i$$

The left-hand-side is what an investor expect to earn from foreign currency deposit: i^{*} is foreign-currency log-deposit rate, S_1 is one-period ahead exchange rate, and S_0 is current exchange rate. The exchange rates are expressed as the number of dollars equivalent to one unit of foreign currency. The right-hand-side i is the U.S. dollar short-term log-deposit rate. FX risk premium is defined as the deviation from the uncovered interest rate parity, i.e., expected excess return to the foreign currency deposit:

(2) $$frp \equiv \mathrm{E}(\rho) \equiv i^{*} - i + \mathrm{E}(\log S_1/S_0)$$

To introduce inflation risk premium, we now turn to Fisher equation:

(3) $i = r + \pi^e$

r is real interest rate, and π^e is the expected inflation rate. Inflation risk premium is defined as the deviation from Fisher equation:

(4) $irp = i - r - \pi^e$

It is the reward to nominal bond investors for being exposed to inflation risk. Nominal bond holders have long exposure to inflation, and to fix the idea, we will consider positive inflation risk premium as typical.[3]

Note that we treat real interest rate r as observable quantity. r is defined as the real yield on an inflation-indexed bond (TIPS). Regardless of whether TIPS are actually traded or not (they are not traded in many countries in the world), conceptually, r can be treated as an observable variable.

Combining the inflation risk premium definition with the FX risk premium definition, we get:

(5) $frp = \mathrm{E}(\log S_1 / S_0) + (\pi^{e*} - \pi^e) + (r^* - r) + irp^* - irp$

While the above formulation is new, similar ideas have been examined in different contexts. For example, international economics textbooks (e.g., Krugman and Obsfeld, 1994) talk about international Fisher equation, from which the above formulation can be easily derived.

The first two terms in the right-hand side is the deviation from *purchasing power parity*. It indicates the increase in the purchasing power of the foreign currency. The first three terms in the right-hand side is the deviation from *real interest rate parity*. Under real interest rate parity, the increase in the purchasing power of the foreign currency, $\mathrm{E}(\log S_1 / S_0) + (\pi^{e*} - \pi^e)$ would be completely offset by real interest rate differential, $(r^* - r)$, and the sum of the two would be zero. When the sum of the two is not zero, it indicates FX risk premium in real term. So we call it real FX risk premium (real FX risk premium can be also described as the expected return to inflation-hedged FX investors):

(6) $rfrp \equiv \mathrm{E}(\log S_1 / S_0) + (\pi^{e*} - \pi^e) + (r^* - r)$

With this definition of real FX risk premium, we may write FX risk premium as the sum of two components, real FX risk premium and inflation risk premium differential:

(7) $frp = rfrp + (irp^* - irp)$

The above decomposition of FX risk premium can be motivated by money neutrality idea as well. If money were neutral, then inflation risk premium would be zero, and all the FX risk premium can be thought of as real FX risk premium. That is, real FX risk premium is the part of FX risk premium that is

[3] As Bekaert and Wang (2010) explain, the inflation risk premium may well be negative, if marginal utility of inves tors is high when inflation rate is high. For example, Balduzzi and Moneta (2017) show that during the post-finan cial crisis period with a negative stock-bond correlation the inflation risk premium can become negative.

not attributable to the violation of money neutrality. Inflation risk premium differential picks up the consequence of the violation of money neutrality.

B. Hypotheses

The empirical pattern than we would like to explain is the following: short-term nominal rate differential $i_{s,t}^{*} - i_{s,t}$ is positively correlated with short-term FX excess return, ρ_{t+1} (one month ahead return), and negatively correlated with long-term FX excess return, $\rho_{t+1} + \cdots + \rho_{t+h}$ (h being 60 or so). In terms of covariances, we may write:

(8) $\mathrm{cov_t}\left(i_{s,t}^{*} - i_{s,t}, \rho_{t+1}\right) = \mathrm{cov_t}\left(i_{s,t}^{*} - i_{s,t}, E_t(\rho_{t+1})\right) > 0$

(9) $\mathrm{cov_t}\left(i_{s,t}^{*} - i_{s,t}, \sum_{j=1}^{h} \rho_{t+j}\right) = \mathrm{cov_t}\left(i_{s,t}^{*} - i_{s,t}, E_t\left(\sum_{j=1}^{h} \rho_{t+j}\right)\right) < 0$, h being 60 or so

Our explanation is the following: when foreign short-term interest rate $i_{s,t}^{*}$ goes up (reflecting monetary tightening in the foreign country), foreign short-term real rate $r_{s,t}^{*}$ rises due to price stickiness. In the long-end of the term structure, foreign long-term real rate $r_{L,t}^{*}$ does not move much due to long-term money neutrality, and foreign long-term inflation expectation ${\pi_{L,t}^{e}}^{*}$ and inflation risk premium $irp_{L,t}^{*}$ goes down. Short-term FX excess return ρ_{t+1} covaries with real rate differential $r_{s,t}^{*} - r_{s,t}$, and h-period FX excess return $\sum_{j=1}^{h} \rho_{t+j}$ covaries with long-term inflation risk premium differential $irp_{L,t}^{*} - irp_{L,t}$. In terms of covariances, we expect:

(10) $\mathrm{cov_t}\left(i_{s,t}^{*} - i_{s,t}, r_{s,t}^{*} - r_{s,t}\right) > 0$

(11) $\mathrm{cov_t}\left(r_{s,t}^{*} - r_{s,t}, E_t(\rho_{t+1})\right) > 0$

(12) $\mathrm{cov}\left(i_{s,t}^{*} - i_{s,t}, irp_{L,t}^{*} - irp_{L,t}\right) < 0$

(13) $\mathrm{cov_t}\left(irp_{L,t}^{*} - irp_{L,t}, E_t\left(\sum_{j=1}^{h} \rho_{t+j}\right)\right) > 0$

We will check Eqs. (8) and (9), but they are not our main concern as these covariances are reported by Engel (2016). (10) is a well established fact, and Eq. (11) is almost immediate from Eq. (12). So, we will not concern ourselves with these two.

Ang et al. (2008) report what amounts to Eq. (12) for the U.S. All we need to do is to check that these patterns survive when we consider a pair of countries at the same time. Evans and Marshall (1998), Drakos (2001), and Berument and Froyen (2006) find that monetary tightening does not affect long-term nominal rate much. Such findings can be consistent with Eq. (12); long-term real rate may go up mildly and inflation compensation may go down. Stronger support for Eq. (12) comes from Romer and Romer (2000) and Ellingsen and Soderstrom (2001, 2003), who suggest that monetary tightening lowers long-term nominal rates once the endogeneity (why central bank decides to tighten money supply in the first place) is properly taken care of. That is, when inflation expectation is high, monetary tightening follows. The net effect of the policy is a lower long-term rate, but it may appear to untrained eye that the effect is opposite. Kliesen and Schmid (2004) and Kiley (2008) report findings consistent with this idea.

For the preliminary analysis, we will not estimate inflation risk premium. (This requires fitting the yield curve via a structural model). For now, we will use breakeven inflation rate $\pi_{L,t}^{B}$ (also known as inflation compensation), which is the sum of inflation expectation and inflation risk premium. Given that inflation expectation is not very volatile, most of the fluctuation in breakeven inflation is in fact the fluctuation in inflation risk premium (Sack and Elsasser, 2004; Gurkaynak, Sack, Wright, 2008; Duddley, Roush, and Ezer, 2009; Abrahams, Adrian, Crump, and Moench, 2013). For easy reference, we re-state the hypotheses of main interest below:

Hypothesis 1. Short-term nominal rate differential is negatively correlated with long-term breakeven inflation rate differential, i.e.,

$$\text{(14)} \qquad \mathrm{cov}\left(i_{s,t}^{*} - i_{s,t}, {\pi_{L,t}^{B}}^{*} - \pi_{L,t}^{B}\right) < 0$$

Hypothesis 2. Long-term breakeven inflation rate differential is positively correlated with long-term FX excess return, i.e.

$$\text{(15)} \qquad \mathrm{cov_t}\left({\pi_{L,t}^{B}}^{*} - \pi_{L,t}^{B}, \textstyle\sum_{j=1}^{h} \rho_{t+j}\right) = \mathrm{cov_t}\left({\pi_{L,t}^{B}}^{*} - \pi_{L,t}^{B}, E_t\left(\textstyle\sum_{j=1}^{h} \rho_{t+j}\right)\right) > 0$$

4. Evidences from the USD-GBP Pair

We verify the two hypothesis stated in the previous section from the USD-GBP data. Working with monthly data, when h is 60, direct computation of covariances leads to extremely imprecise estimates, so adopting VECM, as in Engel (2016), becomes useful. We present the results based on direct calculation as well as VECM.

A. Direct Computation

We have collected data for U.S. and U.K. Real yield curves for these countries are readily available in the web sites of the central banks. For the short rate $i_{s,t}$, we have collected federal funds rates/official bank rates as well as one month and three month interbank rates. It turned out that it does not really matter which one we use. So, below we discuss the results based on three month interbank rates. For the long-term real rate and breakeven inflation rates, we considered 5, 10, and 20 year rates, and obtained mostly comparable results. So, below we focus on the results based on 10 year rates. The U.S. real yield curve is described in Gurkaynak, Sack, Wright (2008). The U.K. real yield curve is described in the web site of Bank of England. We use zero-coupon yields rather than par yields.

The results reported in Table 1 are consistent with Eqs. (8) and (9). Short-term nominal rate differentials are positively correlated with short-term FX excess returns, but negatively correlated with 5-year FX excess returns. Correlations are not statistically significant, but as mentioned above, this is to be expected. Engel (2016) also report similar results when VECM is not adopted.

[Table 1 about here]

Table 2 shows the evidence for Hypothesis 1. Short-term nominal rate differentials are negatively correlated with 10-year breakeven inflation rates. This correlation is statistically significant.

[Table 2 about here]

The last row of Table 3 shows Hypothesis 2. 10-year breakeven inflation rates are positively correlated with long-term FX excess returns. Again, statistical significance is low, but that is to be expected without VECM.

[Table 3 about here]

B. VECM-Based Computation

To improve the precision of the regression analysis reported in the previous section, we estimate the VECM for exchange rates, from which we obtain estimates of long-term FX excess returns.

Our calculation of $E_t\left(\sum_{j=1}^{h} \rho_{t+j}\right)$ differs from Engel's in two respects. First, since we have values for long-term real interest rate and breakeven inflation rate from the indexed bond prices, we use these values in place of VECM-computed values. That is, instead of using

$$(16) \qquad \hat{E}_t\left(\sum_{j=1}^{h} \rho_{t+j}\right) = \widehat{\mathrm{E}}_{\mathrm{t}}^{VECM}\left(\log \frac{S_{t+h}}{S_{t+1}}\right) + \hat{E}_t^{VECM}\left(\sum_{j=1}^{h} r_{S,t+j-1}^{*} - r_{S,t+j-1} + \pi_{S,t+j}{}^{*} - \pi_{S,t+j}\right)$$

we use

$$(17) \qquad \hat{E}_t\left(\sum_{j=1}^{h} \rho_{t+j}\right) = \widehat{\mathrm{E}}_{\mathrm{t}}^{VECM}\left(\log \frac{S_{t+h}}{S_{t+1}}\right) + r_{L,t+j-1}^{*} - r_{L,t+j-1} + \pi_{L,t+j}^{B}{}^{*} - \pi_{L,t+j}^{B}$$

Engel has noted that the sum of expected short rates is not identical to the expected long rate. Given the availability of the latter, it makes more sense to use the latter.

The second departure from Engel's calculation is that we compute 60-month excess return $E_t\left(\sum_{j=1}^{60} \rho_{t+j}\right)$ instead of infinite horizon excess return $E_t\left(\sum_{j=1}^{\infty} \rho_{t+j}\right)$. This allows us to use the observed values of long-term real interest rate and breakeven inflation rate.

Our VECM implementation is identical to Engel's. The VECM can be written in terms of

$$(18) \qquad \mathrm{x_t} = \begin{pmatrix} s_t \\ p_t^* - p_t \\ i_t^* - i_t \end{pmatrix}$$

where s_t is the log exchange rate and p_t^* and p_t are price levels in the UK and in the US, respectively. The purchasing power parity is assumed to hold in the long run so that the log real exchange rate $q_t = s_t + p_t^* - p_t$ approaches its long-term mean in the limit. Under this assumption, the VECM can be restated as a VAR of the following variables:

$$(19) \qquad y_\mathrm{t} = \begin{pmatrix} q_t \\ \pi_t^* - \pi_t \\ i_t^* - i_t \end{pmatrix}$$

The VAR formulation is easier to implement as it allows us to calculate h-period ahead forecast in a simple way.

In Table 4 below, we report the regression of $\hat{E}_t\left(\sum_{j=1}^{60} \rho_{t+j}\right)$ on ${\pi_{L,t+j}^B}^* - \pi_{L,t+j}^B$. We use two variants of $\hat{E}_t\left(\sum_{j=1}^{60} \rho_{t+j}\right)$. $E_t^B\left(\sum_{j=1}^{60} \rho_{t+j}\right)$ is as described above. $E_t^A\left(\sum_{j=1}^{60} \rho_{t+j}\right)$ uses the realized FX rates instead of VECM estimate. That is,

$$(20) \qquad E_t^A\left(\sum_{j=1}^{60} \rho_{t+j}\right) = \log \frac{s_{t+60}}{s_{t+1}} + r_{L,t+j-1}^* - r_{L,t+j-1} + {\pi_{L,t+j}^B}^* - \pi_{L,t+j}^B$$

$$(21) \qquad E_t^B\left(\sum_{j=1}^{60} \rho_{t+j}\right) = \hat{\mathrm{E}}_\mathrm{t}^{VECM}\left(\log \frac{s_{t+60}}{s_{t+1}}\right) + r_{L,t+j-1}^* - r_{L,t+j-1} + {\pi_{L,t+j}^B}^* - \pi_{L,t+j}^B$$

This allows us to see the improvement in precision due to VECM more clearly.

[Table 4 about here]

Adopting VECM, the correlation between the long-term breakeven inflation rate and the long-term FX excess return became significant. We plan to adjust *t*-statistic using a bootstrap method.

5. Evidences from Other Currency Pairs

The U.S and the U.K. are the two countries with the most reliable data on breakeven inflation rates. We were able to obtain breakeven inflation rates for other countries via Bloomberg, but the series are relatively short and have many missing values. While we have some questions on the reliability of these data, we repeated our analysis using these data to get some evidence of whether hypotheses 1 and 2 are likely to be satisfied in other currency pairs as well.

From Bloomberg, we have collected data for four additional currencies: Canadian dollar (CAD), Swedish Krone (SEK), Japanese yen (JPY), and Australian dollar (AUD). We did not include the euro as it is not obvious which country's bond market to look at. We were not able to find necessary data for other major currencies such as Swiss franc. See the table in the Appendix for full description of data that we collected.

Table 5 shows the computation regarding Eqs. (8) and (9). The results do not support Eq. (8). Short rate differentials are not strongly positively correlated with short-term excess returns. On the other hand, the results strongly support Eq. (9). Short rate differentials are strongly negatively correlated with long-term excess returns.

[Table 5 about here]

Table 6 shows the evidence for Hypothesis 1. We presents two sets of estimates. The first set (b and t without asterisk) is from the unmodified regression where y variable is regressed on x variable and the constant term. For the second set (b and t with asterisk), we include dummy variables for contiguous blocks of months. As mentioned earlier, breakeven inflation rate series have many missing values, sometimes for substantial periods of time. If the missing values appear randomly, it will not affect the consistency of the slope estimate. However, if the missing values appear non-randomly (which is more likely the case), then the slope estimate may not be consistent. To reduce the potential effect of missing values, we allowed each contiguous block of data to have a separate intercept term via a dummy variable. Without dummy variables, the estimated coefficient is negative only for two out of four pairs. With dummy variables, however, the estimated coefficient is always negative, and it is significant for three out of four pairs, supporting Hypothesis 1.

[Table 6 about here]

Table 7 shows the evidence for Hypothesis 2. The evidence is quite strong. Breakeven inflation rate differentials are shown to be strongly positively correlated with long-term FX excess returns across currency pairs.

[Table 7 about here]

6. Plan for Further Analysis

The approach taken by Abrahams et al. (2013), which is based on the linear regression estimation of affine term structure models introduced by Adrian, Crump, and Moench (2013), allows us to estimate inflation risk premium controlling for liquidity premium from TIPs and treasury data. We will adopt this approach and repeat our analysis with inflation risk premium estimates.

Appendix 1. Data

Table A1 includes description of data that we collected.

[Table A1 about here]

Appendix 2. VECM

Engel's Eq. (6) is

$$\Delta \mathrm{x_t} = Gx_{t-1} + C_0 + C_1 \Delta \mathrm{x_{t-1}} + C_2 \Delta x_{t-2} + C_3 \Delta x_{t-3} + u_t$$

where

$$\mathrm{x_t} = \begin{pmatrix} s_t \\ p_t^R \\ i_t^R \end{pmatrix}$$

and

$$\mathrm{G} = \begin{pmatrix} g_{11} & -g_{11} & g_{13} \\ g_{21} & -g_{21} & g_{23} \\ g_{31} & -g_{32} & g_{33} \end{pmatrix}$$

The actual estimation is done via the following equation:

$$\mathrm{y_t} = D_0 + D_1 \mathrm{y_{t-1}} + D_2 y_{t-2} + D_3 y_{t-3} + D_4 y_{t-4} + v_t$$

where

$$\mathrm{y_t} = \begin{pmatrix} q_t \\ \pi_t^R \\ i_t^R \end{pmatrix}$$

and

$$\mathrm{D_4} = \begin{pmatrix} d_{4,11} & 0 & d_{4,13} \\ d_{4,21} & 0 & d_{4,23} \\ d_{4,31} & 0 & d_{4,33} \end{pmatrix}$$

The relationship between $(\mathrm{G}, \mathrm{C_0}, C_1, C_2, C_3)$ and $(\mathrm{D_0}, D_1, D_2, D_3, D_4)$ are as follows. Define matrices F and H as

$$\mathrm{F} = \begin{pmatrix} 1 & -1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

and

$$\mathrm{H} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Note that

$$\mathrm{F}^{-1} = \begin{pmatrix} 1 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

After some tedious algebra, one can verify

$$\begin{aligned} \mathrm{D}_0 &= FC_0 \\ \mathrm{D}_1 &= F(C_1F_1^{-1} + GH + H) \\ \mathrm{D}_2 &= \mathrm{F}(C_2F^{-1} - C_1H) \\ \mathrm{D}_3 &= \mathrm{F}(C_3F^{-1} - C_2H) \\ \mathrm{D}_4 &= -\mathrm{FC}_3H \end{aligned}$$

Or

$$\begin{aligned} F^{-1}\mathrm{D}_0 &= C_0 \\ F^{-1}\mathrm{D}_1 &= C_1F_1^{-1} + GH + \mathrm{H} \\ F^{-1}\mathrm{D}_2 &= C_2F^{-1} - C_1H \\ F^{-1}\mathrm{D}_3 &= C_3F^{-1} - C_2H \\ \mathrm{F}^{-1}\mathrm{D}_4 &= -\mathrm{C}_3H \end{aligned}$$

To recover C_1, C_2, C_3, one requires a bit more algebra because H is nonsingular. Since

$$\mathrm{F}^{-1}\mathrm{H} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} = H$$

and

$$\mathrm{HH} = \mathrm{H}$$

by pre-multiplying the three equations in the middle by H,

$$F^{-1}\mathrm{D}_1H = (C_1 + G + I)H = (C_1 + G + I)\begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$F^{-1}\mathrm{D}_2H = (C_2 - C_1)H = (C_2 - C_1)\begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$F^{-1}\mathrm{D}_3H = (C_3 - C_2)H = (C_3 - C_2)\begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

From the last equation,

$$\mathrm{F}^{-1}\mathrm{D}_4 = -\mathrm{C}_3H = -C_3\begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

The above equations determine the first and the third columns of $\mathrm{C}_1, C_2, C_3, G$.

Since

$$H(I - H) = \mathrm{H}\begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix} = 0$$

and

$$\mathrm{F}^{-1}(I - H) = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix} = F^{-1} - H$$

when we post-multiply the same three equations by $\mathrm{I} - \mathrm{H}$,

$$F^{-1}\mathrm{D}_1(I - H) = \mathrm{C}_1(F^{-1} - H) = \mathrm{C}_1\begin{pmatrix} 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$F^{-1}\mathrm{D}_2(I-H)=\mathrm{C}_2(F^{-1}-H)=\mathrm{C}_2\begin{pmatrix}0&1&0\\0&1&0\\0&0&0\end{pmatrix}$$

$$F^{-1}\mathrm{D}_3(I-H)=\mathrm{C}_3(F^{-1}-H)=\mathrm{C}_3\begin{pmatrix}0&1&0\\0&1&0\\0&0&0\end{pmatrix}$$

Also, from the restriction imposed on G,

$$0=\mathrm{G}(\mathrm{F}^{-1}-H)=G\begin{pmatrix}0&1&0\\0&1&0\\0&0&0\end{pmatrix}$$

The above equation determines the second column of C_1, C_2, C_3 once the first column has been determined.

Now, to obtain C_3, subtract the equation starting with $\mathrm{F}^{-1}D_4$ from the equation starting with $F^{-1}\mathrm{D}_3(I-H)$:

$$F^{-1}\mathrm{D}_3(I-H)-\mathrm{F}^{-1}\mathrm{D}_4=C_3F^{-1}$$

which implies

$$C_3=F^{-1}[\mathrm{D}_3(I-H)-D_4]\mathrm{F}$$

To obtain C_2, add the equations starting with $F^{-1}\mathrm{D}_3H$ and $\mathrm{F}^{-1}D_4$, and subtract the sum from the equation starting with $F^{-1}\mathrm{D}_2(I-H)$:

$$F^{-1}\mathrm{D}_2(I-H)-(F^{-1}\mathrm{D}_3H+\ \mathrm{F}^{-1}D_4)=\mathrm{C}_2(F^{-1}-H)+C_2H$$

which implies

$$\mathrm{C}_2=F^{-1}[D_2(I-H)-D_3H-D_4]F$$

To obtain C_1, add the equations starting with $\mathrm{F}^{-1}D_4$, $F^{-1}\mathrm{D}_3H$, and $F^{-1}\mathrm{D}_2H$, and subtract the sum from the equation starting with $F^{-1}\mathrm{D}_1(I-H)$:

$$F^{-1}\mathrm{D}_1(I-H)-(F^{-1}D_2H+F^{-1}\mathrm{D}_3H+\ \mathrm{F}^{-1}D_4)=\mathrm{C}_1(F^{-1}-H)+C_1H$$

which implies

$$\mathrm{C}_1=F^{-1}[D_1(I-H)-D_2H-D_3H-D_4]F$$

To obtain G, add the equations starting with $\mathrm{F}^{-1}D_4$, $F^{-1}\mathrm{D}_3H$, $F^{-1}\mathrm{D}_2H$, and $\mathrm{F}^{-1}D_1H$, and add the sum from the equation starting with 0:

$$0+(F^{-1}D_1H+F^{-1}D_2H+F^{-1}\mathrm{D}_3H+\ \mathrm{F}^{-1}D_4)=G(F^{-1}-H)+(G+I)H$$

which implies

$$\mathrm{G}=F^{-1}[D_1H+D_2H+D_3H+D_4-I]F$$

Calculation of infinite sum is easier with this formulation. Let us re-write the equation using "big matrices":

$$\begin{pmatrix}y_t\\y_{t-1}\\y_{t-2}\\y_{t-3}\end{pmatrix}=\begin{pmatrix}D_0\\0\\0\\0\end{pmatrix}+\begin{pmatrix}D_1&D_2&D_3&D_4\\I&0&0&0\\0&I&0&0\\0&0&I&0\end{pmatrix}\begin{pmatrix}y_{t-1}\\y_{t-2}\\y_{t-3}\\y_{t-4}\end{pmatrix}+\begin{pmatrix}v_t\\v_{t-1}\\v_{t-2}\\v_{t-3}\end{pmatrix}$$

Or

$$\mathrm{z_t}=A_0+Az_{t-1}+\omega_t$$

After "de-meaning" the variable:

$$\tilde{\mathrm{z}}_{\mathrm{t}}=A\tilde{z}_{t-1}+\omega_t$$

Then

$$\tilde{z}_{t+k} = A^k z_t + A^{k-1}\omega_{t+1} + \cdots + A\omega_{t+k-1} + \omega_{t+k}$$

and

$$\mathrm{E_t}[\tilde{z}_{t+k}] = A^k z_t$$
$$\mathrm{E}[\tilde{z}_t + \cdots + \tilde{z}_{t+k}] = (I + \cdots + A^k)z_t$$
$$\mathrm{E_t}\left[\sum_{j=0}^{\infty} \tilde{z}_{t+j}\right] = (I - A)^{-1}\tilde{z}_t$$

Consider Engel's Eq. (9):

$$\widehat{\mathrm{E}}_t\left[\sum_{j=0}^{\infty}\left(\rho_{t+1+j} - \bar{\rho}\right)\right] = \zeta_\rho + \beta_\rho(\hat{r}_t^* - \hat{r}_t) + u_{\rho t}$$

From Eq. (3), the left-hand-side of the above equation is:

$$\widehat{\mathrm{E}}_t\left[\sum_{j=0}^{\infty}\left(\rho_{t+1+j} - \bar{\rho}\right)\right] = \widehat{\mathrm{E}}_t\left[\sum_{j=0}^{\infty}\left(r_{t+j}^* - r_{t+j} - \overline{r^* - r}\right)\right] - \left(q_t - \lim_{k\to\infty} E_t q_{t+k}\right)$$

Given the stationarity assumption for $\mathrm{q_t}$,

$$\widehat{\mathrm{E}}_t\left[\sum_{j=0}^{\infty}\left(\rho_{t+1+j} - \bar{\rho}\right)\right] = \widehat{\mathrm{E}}_t\left[\sum_{j=0}^{\infty}\left(r_{t+j}^* - r_{t+j} - \overline{r^* - r}\right)\right] - (q_t - \bar{q})$$

The first term in the right hand side can be obtained as follows:

$$\widehat{\mathrm{E}}_t\left[\sum_{j=0}^{\infty}\left(r_{t+j}^* - r_{t+j} - \overline{r^* - r}\right)\right] = \widehat{\mathrm{E}}_t\left[\sum_{j=0}^{\infty}\left(i_{t+j}^* - i_{t+j} - \overline{\imath^* - \imath}\right)\right] - \widehat{\mathrm{E}}_t\left[\sum_{j=0}^{\infty}\left(\pi_{t+1+j}^* - \pi_{t+1+j} - \overline{\pi^* - \pi}\right)\right]$$
$$= \mathrm{e_3}'\left(I - \hat{A}\right)^{-1}\tilde{z}_t - e_2'\widehat{\mathrm{E}}_\mathrm{t}\left[\left(I - \hat{A}\right)^{-1}\tilde{z}_{t+1}\right]$$
$$= \mathrm{e_3}'\left(I - \hat{A}\right)^{-1}\tilde{z}_t - e_2'\left(I - \hat{A}\right)^{-1}A\tilde{z}_t$$

Let us now consider the formula again paying attention to the actual data to be used in the estimation. Note first that given the restriction on $\mathrm{D_4}$, we do not need the value for π_1^R. Thus, no data is lost from the re-formulation.

Let Y be the matrix of data. Let us denote the time period by $1, \cdots, \mathrm{T}$. We need matrices to represent the data excluding the first and last several rows. Let us use the notation $\mathrm{Y_{1:T-4}}, Y_{2:T-3}, \mathrm{Y_{3:T-2}}, Y_{4:T-1}, Y_{5:T}$ to indicate data from row 1 to row $\mathrm{T} - 4$, etc. Similarly, $\mathrm{Y_{1:T-3}}, Y_{2:T-2}, Y_{3:T-1}, Y_{4:T}$ to indicate data from row 1 to row $\mathrm{T} - 3$, etc.

The VECM estimation is done from the following equation:

$$\mathrm{Y_{5:T}} = D_0 + D_1 Y_{4:T-1} + D_2 Y_{3:T-2} + D_3 Y_{2:T-3} + D_4 Y_{1:T-4} + v$$

From the estimated coefficients, we form the big matrix A:

$$\widehat{\mathrm{A}} = \begin{pmatrix} \widehat{D}_1 & \widehat{D}_2 & \widehat{D}_3 & \widehat{D}_4 \\ I & 0 & 0 & 0 \\ 0 & I & 0 & 0 \\ 0 & 0 & I & 0 \end{pmatrix}$$

Vector $\mathrm{z_t}$ can be assembled only from $\mathrm{t} = 4$. So we form matrix Z as

$$\mathrm{Z} = [Y_{4:T}, Y_{3:T-1}, Y_{2:T-2}, Y_{1:T-3}]$$

Then time-series of $\widehat{\mathrm{E}}_t\left[\sum_{j=0}^{\infty}\left(r_{t+j}^* - r_{t+j} - \overline{r^* - r}\right)\right]$ for $\mathrm{t} = 4, \cdots, \mathrm{T}$ can be assembled into a row vector as follows:

$$\mathrm{e}_3'\left(I - \hat{A}\right)^{-1}\tilde{Z}' - e_2'\left(I - \hat{A}\right)^{-1}A\tilde{Z}'$$

where $\tilde{Z}$ is obtained after subtracting means from Z. The time series of $(q_t - \bar{q})$ can be assembled into the following row vector

$$\mathrm{e}_1'\tilde{Z}'$$

Thus, the time-series of $\widehat{\mathrm{E}}_t\left[\sum_{j=0}^{\infty}\left(\rho_{t+1+j} - \bar{\rho}\right)\right]$ is

$$\mathrm{e}_3'\left(I - \hat{A}\right)^{-1}\tilde{Z}' - e_2'\left(I - \hat{A}\right)^{-1}A\tilde{Z}' - \mathrm{e}_1'\tilde{Z}'$$

The time-series of $(\hat{r}_t^* - \hat{r}_t)$ is

$$\mathrm{e}_3'\tilde{Z}' - e_2'A\tilde{Z}$$

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Figure 1. Response of Currency to Monetary Expansion: Illustration

The plots illustrate the following scenario: The central bank increased money supply at time 1. The price level does not change at time 1; it goes up at time 2 and comes back to the initial level at time 3. The short-term (one-period) interest rate drops mildly at time 1, goes up significantly at time 2 (reflecting inflation), and comes back to the initial level at time 3.

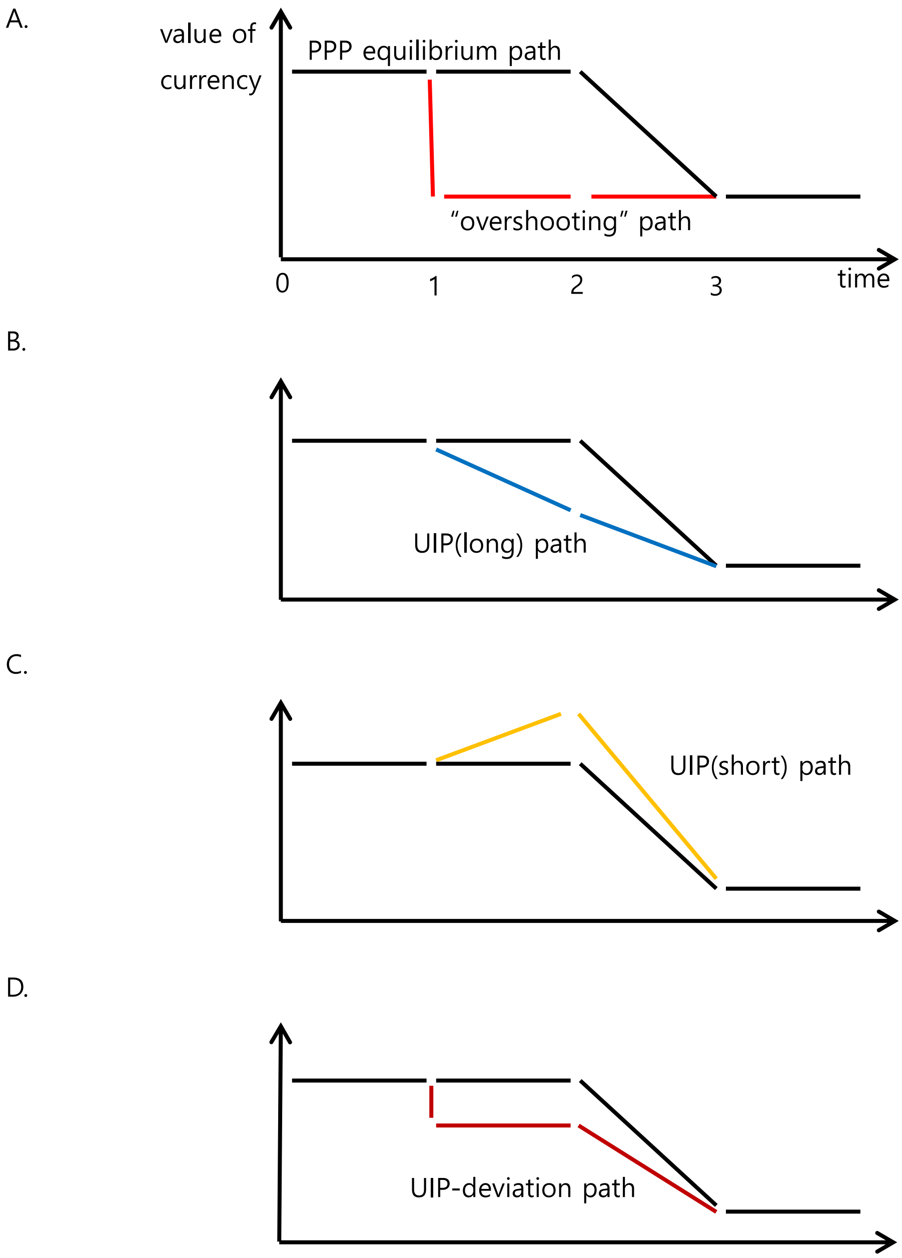

Table 1. Short-term nominal rate differential vs. FX excess returns: USD-GBP

The table reports the coefficient estimate (b) and its t statistic in the regression of Y on X. No adjustment is made in calculation of t statistic. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Y	X	sample period	N	b	t	
ρ_{t+1}	$i_{S,t}^* - i_{S,t}$	1999m1 ~ 2011m6	150	1.16	0.55	
$\rho_{t+1}+\cdots+\rho_{t+12}$	$i_{S,t}^* - i_{S,t}$	1999m1 ~ 2011m6	150	8.34	0.98	
$\rho_{t+1}+\cdots+\rho_{t+24}$	$i_{S,t}^* - i_{S,t}$	1999m1 ~ 2011m6	150	30.08	2.53	***
$\rho_{t+1}+\cdots+\rho_{t+36}$	$i_{S,t}^* - i_{S,t}$	1999m1 ~ 2011m6	150	54.24	4.26	***
$\rho_{t+1}+\cdots+\rho_{t+48}$	$i_{S,t}^* - i_{S,t}$	1999m1 ~ 2011m6	150	26.48	1.74	*
$\rho_{t+1}+\cdots+\rho_{t+60}$	$i_{S,t}^* - i_{S,t}$	1999m1 ~ 2011m6	150	-6.50	-0.38	

Table 2. Short-term nominal rate differential vs. long-term breakeven inflation rate differential: USD-GBP

The table reports the coefficient estimate (b) and its t statistic in the regression of Y on X. No adjustment is made in calculation of t statistic. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Y	X	sample period	N	b	t	
$\pi_{L,t}* - \pi_{L,t}$	$i_{S,t}* - i_{S,t}$	1999m2 ~ 2016m6	210	-0.12	-6.00	***

Table 3. Long-term breakeven inflation rate differential vs. FX excess returns: USD-GBP

The table reports the coefficient estimate (b) and its t statistic in the regression of Y on X. No adjustment is made in calculation of t statistic. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Y	X	sample period	N	b	t	
ρ_{t+1}	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	1999m1 ~ 2011m6	150	-17.21	-2.15	**
$\rho_{t+1}+\cdots+\rho_{t+12}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	1999m1 ~ 2011m6	150	-152.76	-5.05	***
$\rho_{t+1}+\cdots+\rho_{t+24}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	1999m1 ~ 2011m6	150	-265.49	-6.44	***
$\rho_{t+1}+\cdots+\rho_{t+36}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	1999m1 ~ 2011m6	150	-185.37	-3.74	***
$\rho_{t+1}+\cdots+\rho_{t+48}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	1999m1 ~ 2011m6	150	-33.18	-0.56	
$\rho_{t+1}+\cdots+\rho_{t+60}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	1999m1 ~ 2011m6	150	42.82	0.66	

Table 4. Long-term breakeven inflation rate differential vs. VECM-based FX excess returns: USD-GBP

The table reports the coefficient estimate (b) and its t statistic in the regression of Y on X. No adjustment is made in calculation of t statistic. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Y	X	sample period	N	b	t	
$E_t^A(\rho_{t+1}+\cdots+\rho_{t+60})$	$\pi_{L,t}^{B^*} - \pi_{L,t}^{B}$	1999m1 ~ 2011m6	150	59.73	1.02	
$E_t^B(\rho_{t+1}+\cdots+\rho_{t+60})$	$\pi_{L,t}^{B^*} - \pi_{L,t}^{B}$	1999m8 ~ 2015m3	188	48.09	2.16	**

Table 5. Short-term nominal rate differential vs. FX excess returns: Other currency pairs

The table reports the coefficient estimate (b) and its t statistic in the regression of Y on X. No adjustment is made in calculation of t statistic. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

A. USD-CAD

Y	X	sample period	N	b	t	
ρ_{t+1}	$i_{S,t}^* - i_{S,t}$	2000m3 ~ 2017m2	204	-1.08	-0.37	
$\rho_{t+1}+\cdots+\rho_{t+12}$	$i_{S,t}^* - i_{S,t}$	2000m3 ~ 2016m3	193	-8.62	-0.85	
$\rho_{t+1}+\cdots+\rho_{t+24}$	$i_{S,t}^* - i_{S,t}$	2000m3 ~ 2015m3	181	5.41	0.37	
$\rho_{t+1}+\cdots+\rho_{t+36}$	$i_{S,t}^* - i_{S,t}$	2000m3 ~ 2014m3	169	-1.56	-0.08	
$\rho_{t+1}+\cdots+\rho_{t+48}$	$i_{S,t}^* - i_{S,t}$	2000m3 ~ 2013m3	157	-8.39	-0.39	
$\rho_{t+1}+\cdots+\rho_{t+60}$	$i_{S,t}^* - i_{S,t}$	2000m3 ~ 2012m3	145	-15.91	-0.69	

B. USD-SEK

Y	X	sample period	N	b	t	
ρ_{t+1}	$i_{S,t}^* - i_{S,t}$	2004m1 ~ 2017m2	158	-2.06	-0.93	
$\rho_{t+1}+\cdots+\rho_{t+12}$	$i_{S,t}^* - i_{S,t}$	2004m1 ~ 2016m3	147	-24.87	-3.13	***
$\rho_{t+1}+\cdots+\rho_{t+24}$	$i_{S,t}^* - i_{S,t}$	2004m1 ~ 2015m3	135	-23.22	-2.27	**
$\rho_{t+1}+\cdots+\rho_{t+36}$	$i_{S,t}^* - i_{S,t}$	2004m1 ~ 2014m3	123	-14.60	-1.39	
$\rho_{t+1}+\cdots+\rho_{t+48}$	$i_{S,t}^* - i_{S,t}$	2004m1 ~ 2013m3	111	-39.18	-3.36	***
$\rho_{t+1}+\cdots+\rho_{t+60}$	$i_{S,t}^* - i_{S,t}$	2004m1 ~ 2012m3	99	-56.09	-5.62	***

C. USD-JPY

Y	X	sample period	N	b	t	
ρ_{t+1}	$i_{S,t}^* - i_{S,t}$	2004m4 ~ 2017m2	155	-0.27	-0.18	
$\rho_{t+1}+\cdots+\rho_{t+12}$	$i_{S,t}^* - i_{S,t}$	2004m4 ~ 2016m3	144	-5.28	-0.87	
$\rho_{t+1}+\cdots+\rho_{t+24}$	$i_{S,t}^* - i_{S,t}$	2004m4 ~ 2015m3	132	-36.29	-3.94	***
$\rho_{t+1}+\cdots+\rho_{t+36}$	$i_{S,t}^* - i_{S,t}$	2004m4 ~ 2014m3	120	-80.48	-7.36	***
$\rho_{t+1}+\cdots+\rho_{t+48}$	$i_{S,t}^* - i_{S,t}$	2004m4 ~ 2013m3	108	-126.90	-13.38	***
$\rho_{t+1}+\cdots+\rho_{t+60}$	$i_{S,t}^* - i_{S,t}$	2004m4 ~ 2012m3	96	-145.96	-24.32	***

D. USD-AUD

Y	X	sample period	N	b	t	
ρ_{t+1}	$i_{S,t}^* - i_{S,t}$	2000m3 ~ 2017m2	204	1.01	0.45	
$\rho_{t+1}+\cdots+\rho_{t+12}$	$i_{S,t}^* - i_{S,t}$	2000m3 ~ 2016m3	193	13.63	1.59	
$\rho_{t+1}+\cdots+\rho_{t+24}$	$i_{S,t}^* - i_{S,t}$	2000m3 ~ 2015m3	181	3.09	0.26	
$\rho_{t+1}+\cdots+\rho_{t+36}$	$i_{S,t}^* - i_{S,t}$	2000m3 ~ 2014m3	169	-32.15	-2.32	**
$\rho_{t+1}+\cdots+\rho_{t+48}$	$i_{S,t}^* - i_{S,t}$	2000m3 ~ 2013m3	157	-85.12	-6.01	***
$\rho_{t+1}+\cdots+\rho_{t+60}$	$i_{S,t}^* - i_{S,t}$	2000m3 ~ 2012m3	145	-117.85	-9.78	***

Table 6. Short-term nominal rate differential vs. long-term breakeven inflation rate differential: Other currency pairs

The table reports the coefficient estimate (b) and its t statistic in the regression of Y on X. No adjustment is made in calculation of t statistic. b* and t* are from the regression that does not include a constant term, but instead includes dummy variables for contiguous blocks. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

A. USD-CAD

Y	X	sample period	N	b	t		b*	t*	
$\pi_{L,t}^* - \pi_{L,t}$	$i_{S,t}^* - i_{S,t}$	2000m3 ~ 2017m3	205	-0.04	-1.93	*	-0.04	-1.93	*

B. USD-SEK

Y	X	sample period	N	b	t		b*	t*	
$\pi_{L,t}^* - \pi_{L,t}$	$i_{S,t}^* - i_{S,t}$	2004m1 ~ 2016m7	135	0.01	0.31		-0.04	-1.64	

C. USD-JPY

Y	X	sample period	N	b	t		b*	t*	
$\pi_{L,t}^* - \pi_{L,t}$	$i_{S,t}^* - i_{S,t}$	2004m4 ~ 2016m7	94	0.11	2.76	***	-0.26	-11.35	***

D. USD-AUD

Y	X	sample period	N	b	t		b*	t*	
$\pi_{L,t}^* - \pi_{L,t}$	$i_{S,t}^* - i_{S,t}$	2000m3 ~ 2016m7	143	-0.08	-5.94	***	-0.11	-6.29	***

Table 7. Long-term breakeven inflation rate differential vs. FX excess returns: Other currency pairs

The table reports the coefficient estimate (b) and its t statistic in the regression of Y on X. No adjustment is made in calculation of t statistic. b* and t* are from the regression that does not include a constant term, but instead includes dummy variables for contiguous blocks. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

A. USD-CAD

Y	X	sample period	N	b	t		b*	t*	
ρ_{t+1}	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2008m5 ~ 2016m7	87	10.97	0.55		13.90	0.69	
$\rho_{t+1}+\cdots+\rho_{t+12}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2008m5 ~ 2016m3	83	149.08	3.08	***	175.14	4.06	***
$\rho_{t+1}+\cdots+\rho_{t+24}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2008m5 ~ 2015m3	71	326.49	4.99	***	346.19	5.92	***
$\rho_{t+1}+\cdots+\rho_{t+36}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2008m5 ~ 2013m6	62	471.11	5.75	***	471.11	5.75	***
$\rho_{t+1}+\cdots+\rho_{t+48}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2008m5 ~ 2013m3	59	412.96	3.95	***	412.96	3.95	***
$\rho_{t+1}+\cdots+\rho_{t+60}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2008m5 ~ 2012m3	47	202.82	1.37		202.82	1.37	

B. USD-SEK

Y	X	sample period	N	b	t		b*	t*	
ρ_{t+1}	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2004m1 ~ 2016m7	135	12.10	1.14		14.18	1.31	
$\rho_{t+1}+\cdots+\rho_{t+12}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2004m1 ~ 2016m3	131	93.20	2.78	***	107.02	3.17	***
$\rho_{t+1}+\cdots+\rho_{t+24}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2004m1 ~ 2015m3	119	251.28	5.30	***	270.37	5.78	***
$\rho_{t+1}+\cdots+\rho_{t+36}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2004m1 ~ 2014m3	107	353.49	7.76	***	384.60	8.95	***
$\rho_{t+1}+\cdots+\rho_{t+48}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2004m1 ~ 2013m3	95	368.31	6.52	***	425.48	7.81	***
$\rho_{t+1}+\cdots+\rho_{t+60}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2004m1 ~ 2012m3	83	252.92	3.90	***	429.91	7.00	***

C. USD-JPY

Y	X	sample period	N	b	t		b*	t*	
ρ_{t+1}	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2004m4 ~ 2016m7	94	-0.98	-0.21		0.62	0.08	
$\rho_{t+1}+\cdots+\rho_{t+12}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2004m4 ~ 2016m3	91	-34.92	-1.95	*	-13.82	-0.51	
$\rho_{t+1}+\cdots+\rho_{t+24}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2004m4 ~ 2015m3	79	-101.01	-3.91	***	-35.91	-1.61	
$\rho_{t+1}+\cdots+\rho_{t+36}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2004m4 ~ 2014m3	67	-143.58	-3.59	***	-12.43	-0.55	
$\rho_{t+1}+\cdots+\rho_{t+48}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2004m4 ~ 2009m5	61	38.90	0.85		133.39	4.72	***
$\rho_{t+1}+\cdots+\rho_{t+60}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2004m4 ~ 2009m5	61	164.44	4.21	***	229.87	7.42	***

D. USD-AUD

Y	X	sample period	N	b	t		b*	t*	
ρ_{t+1}	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2000m3 ~ 2016m7	143	11.47	0.94		17.95	1.41	
$\rho_{t+1}+\cdots+\rho_{t+12}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2000m3 ~ 2016m3	139	71.17	1.82	*	116.43	3.03	***
$\rho_{t+1}+\cdots+\rho_{t+24}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2000m3 ~ 2015m3	127	94.79	1.58		74.26	1.30	
$\rho_{t+1}+\cdots+\rho_{t+36}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2000m3 ~ 2014m3	115	128.19	1.60		35.19	0.59	
$\rho_{t+1}+\cdots+\rho_{t+48}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2000m3 ~ 2013m3	103	221.47	2.26	**	162.68	2.65	***
$\rho_{t+1}+\cdots+\rho_{t+60}$	$\pi_{L,t}^{B*} - \pi_{L,t}^{B}$	2000m3 ~ 2012m3	91	230.34	2.26	**	294.25	6.41	***

Table A1. Data Description

Variable	Currency	Description and source	Frequency and sample period	Notes
Short rate, nominal	USD	3-month LIBOR, as of 11:00am London time (Federal Reserve)	Daily, Jan 4, 1971 ~ Aug 2, 2016	1)
		1-month LIBOR, as of 11:00am London time (Bloomberg)	Daily, Jan 2, 1990 ~ Apr 13, 2017	2)
	GBP	3-month Sterling certificate of deposit rate, mid rate (Bank of England)	Daily, Jan 2, 1975 ~ Aug 2, 2016	1)
	CAD	1-month LIBOR, as of 11:00am London time (Bloomberg)	Daily, Oct 2, 1990 ~ May 31, 2013 (observations missing for some days)	2), 3)
		1-month deposit rate, as of the market closing in London (Bloomberg)	Daily, Aug 21, 1997 ~ Apr 14, 2017 (observations missing for many days)	2), 3)
	SEK	1-month LIBOR, as of 11:00am London time (Bloomberg)	Daily, Jan 24, 2006 ~ Mar 28, 2013	2), 3)
		1-month deposit rate, as of the market closing in London (Bloomberg)	Daily, May 7, 1996 ~ Apr 14, 2017 (observations missing for many days)	2), 3)
	JPY	1-month LIBOR, as of 11:00am London time (Bloomberg)	Daily, Jan 2, 1990 ~ Apr 13, 2017	2)
	AUD	1-month LIBOR, as of 11:00am London time (Bloomberg)	Daily, Jan 5, 1995 ~ May 31, 2013 (observations missing for some days)	2), 3)
		1-month deposit rate, as of the market closing in London (Bloomberg)	Daily, May 14, 1998 ~ Apr 14, 2017	2), 3)
Breakeven inflation rate	USD	10-year breakeven inflation rate implied by zero-coupon, indexed bond prices (see Gurkaynak, Sack, and Knight (2008))	Daily, Jan 4, 1999 ~ Jul 29, 2016	1)
	GBP	10-year breakeven inflation rate implied by zero-coupon, indexed bond prices (Bank of England)	Daily, Jan 2, 1990 ~ Jun 30, 2016	1)
	CAD	10-year breakeven inflation rate implied by zero-coupon, indexed bond prices (Bloomberg)	Daily, May 6, 2008 ~ Apr 11, 2017 (observations missing for many days)	2)
	SEK	10-year breakeven inflation rate implied by zero-coupon, indexed bond prices (Bloomberg)	Daily, Jan 23, 2004 ~ Apr 11, 2017 (observations missing for many days)	2)
	JPY	10-year breakeven inflation rate implied by zero-coupon, indexed bond prices (Bloomberg)	Daily, Apr 15, 2004 ~ Apr 5, 2017 (observations missing for many days)	2)
	AUD	10-year breakeven inflation rate implied by zero-coupon, indexed bond prices (Bloomberg)	Daily, Mar 20, 2000 ~ Apr 11, 2017 (observations missing for many days)	2)

Variable	Currency	Description and source	Frequency and sample period	Notes
FX rate	USD-GBP	dollar-buying rate, as of noon New-York time (Federal Reserve)	Daily, Jan 4, 1971 ~ Jul 22, 2016	1)
	USD-CAD	mid rate, as of the market closing in London (Bloomberg)	Daily, Jan 3, 1990 ~ Apr 14, 2017	2)
	USD-SEK	mid rate, as of the market closing in London (Bloomberg)	Daily, Jan 2, 1990 ~ Apr 14, 2017	2)
	USD-JPY	mid rate, as of the market closing in London (Bloomberg)	Daily, Jan 2, 1990 ~ Apr 14, 2017	2)
	USD-AUD	mid rate, as of the market closing in London (Bloomberg)	Daily, Jan 2, 1990 ~ Apr 25, 2017	2)
Long rate, nominal	USD	Yield of 10-year, zero-coupon, nominal bonds (Federeal Reserve)	Daily, Aug 16, 1971 ~ Jul 29, 2016	1)
	GBP	Yield of 10-year, zero-coupon, nominal bonds (Bank of England)	Daily, Jan 2, 1990 ~ Jun 30, 2016	1)
Inflation rate	USD	CPI inflation rates (see Engel (2016))	Monthly, Feb 1955 ~ Mar 2015	1)
	GBP	CPI inflation rates (see Engel (2016))	Monthly, Feb 1955 ~ Mar 2015	1)

Notes:

1) This series is used in the preparation of Tables 1, 2, 3, and 4.

2) This series is used in the preparation of Tables 5, 6, and 7.

3) When the 1-month libor rate is not available, we imputed the rate using the 1-month deposit rate assuming a constant spread between the 1-month libor rate and the 1-month deposit rate.