Get Real: Interpreting Nominal Exchange Rate Fluctuations*

Richard Clarida
Columbia University

This paper derives a structural relationship between the nominal exchange rate, national price levels, and observed yields on long-maturity inflation-indexed bonds. This relationship can be interpreted as defining the (conditional) risk-neutral fair value of the exchange rate between two countries in which inflation-indexed bonds are issued. We derive a novel, empirically observable measure of the risk premium that can open up a wedge between the observed level of the nominal exchange rate and its risk-neutral fair value. We relate our measure of the risk premium reflected in the level of the nominal exchange rate to the familiar Fama measure of the risk premium reflected in rates of return on foreign currency investments. We take our theory to a data set spanning the period January 2001–February 2011 and study high-frequency, real-time decompositions of pound, euro, and yen exchange rates into their risk-neutral fair value and risk premium components. The relative importance of these two factors varies depending on the subsample studied. However, subsamples in which, contrary to the Meese-Rogoff (1983) puzzle, 30 to 60 percent of the fluctuations in daily exchange rate changes are explained by contemporaneous changes in risk-neutral fair value are not uncommon.

JEL Codes: F31, F32, F37.

*The author is the C. Lowell Harriss Professor of Economics, Columbia University and Global Strategic Advisor, PIMCO. This paper was prepared for the April 22–23, 2011 conference in honor of Benjamin Friedman hosted by the Federal Reserve Bank of Boston. I am indebted to Ben Friedman for so much, not least for providing me with the deep and lasting foundations to do to research in monetary economics, and for teaching me that good economics is more about the questions we seek to answer and not so much about the methodologies we seek to promote. Thank you, Ben.

1. Introduction

This paper derives a structural relationship between the nominal exchange rate, national price levels, and observed yields on long-maturity inflation-indexed bonds. This relationship can be interpreted as defining the risk-neutral fair value of the exchange rate that will prevail in any model—or, more importantly, any real-world economy—in which inflation-indexed bonds are traded. The advantage of this approach is that it does not impose restrictive assumptions (e.g., complete markets, representative agent) on financial market equilibrium, does not require the estimation of a stable linear time-series model for short-term ex ante real interest differentials or expected future inflation, nor does it require that the expectations hypothesis of the term structure hold. We derive a novel, empirically observable measure of the risk premium that can open up a wedge between the observed level of the nominal exchange rate and its risk-neutral fair value. We relate our measure of the risk premium reflected in the level of the nominal exchange rate to the familiar Fama (1984) measure of the risk premium reflected in rates of return on foreign currency investments.

We take our theory to a data set spanning the period January 2001–February 2011 and study high-frequency, real-time decompositions of pound, euro, and yen exchange rates into their risk-neutral fair value and risk premium components. The relative importance of these two factors varies depending on the subsample studied. However, subsamples in which, contrary to the Meese-Rogoff (1983) puzzle, 30 to 60 percent of the fluctuations in daily exchange rate changes are explained by contemporaneous changes in risk-neutral fair value are not uncommon.

2. The Model

We make a minimal number of assumptions. We do not assume complete markets or a representative agent. We do not assume that we know the model, let alone the parameters, that link the present value of macro fundamentals to exchange rate valuation. Under our assumptions, our framework is consistent with almost any underlying model. We assume that, in a global financial equilibrium, there is a functional relationship between the nominal (U.S. dollar) price today of an asset that delivers a random dollar cash flow at some date in the future (for concreteness, ten years hence) and no cash flow at any date other than $t+n$:

$$\rho_t = F_t(N_{t+n}; \Omega_{t,t+n}),$$

where $\Omega_{t,t+n}$ is the conditional probability distribution of the random nominal cash flow from the asset that pays off in n years. We specialize F so that

$$\rho_t = E_t(m_{t,n} N_{t+n}; \Omega_{t,t+n}). \tag{1}$$

So today's price of an asset with random nominal cash flow in n years is the conditional expectation of the product of that cash flow and the random variable $m_{t,n}$.

ASSUMPTION. *$m_{t,n}$ is homogenous in the price levels P_t and P_{t+n}.*

$$m_{t,n} = z_{t,n} \frac{P_t}{P_{t+n}} \tag{2}$$

This is a standard property in many asset pricing models. For example, in Lucas (1982),

$$m_{t,n} = \beta^n \frac{U'(C_{t+n})}{U'(C_t)} \frac{P_t}{P_{t+n}}.$$

Again, we do not require a representative agent, complete markets, or really any additional structure on $z_{t,n}$. This is an intuitive restriction on nominal asset prices that says that the *real* price of the asset today depends upon the *real* value of the cash flow it delivers state by state at maturity and not the price level itself at $t+n$ itself (after, of course, controlling for factors other than the price level itself that are included in $z_{t,n}$).

With this background, consider how to price a zero-coupon inflation-indexed bond that pays off one dollar in n years multiplied by cumulative realized inflation over the next n years.

$$\rho_t = E_t\left(m_{t,n} \cdot 1 \cdot \frac{P_{t+n}}{P_t}\right) = E_t(z_{t,n} \cdot 1) \tag{3}$$

Or, dividing by ρ_t,

$$1 = \{\exp nr_{t,n}\} E_t(z_{t,n}), \tag{4}$$

where $r_{t,n}$ is the continuous compounded known real return on the inflation-indexed bond.

U.S. investors can also obtain U.S. dollar cash flows by investing in a UK inflation-indexed bond and selling the pound proceeds for dollars in n years. Let S_t be the dollar price of a pound and $*$ represent a UK variable. Let $Q_t = S_t P_t^* / P_t$ define the real exchange rate and Q its unconditional mean. Then we have

$$S_t \rho_t^* = E_t \left(m_{t,n} \cdot 1 \cdot S_{t+n} \cdot \frac{P_{t+n}^*}{P_t^*} \right). \tag{5}$$

Or, dividing through,

$$1 = \exp nr_{t,n}^* E_t \left(z_{t,n} \cdot 1 \cdot \frac{Q_{t+n}}{Q_t} \right). \tag{6}$$

With these building blocks we now derive a structural exchange rate equation that will hold in any model that seeks to describe a world in which long-maturity inflation-indexed bonds trade. Since such bonds trade in many countries (United States, United Kingdom, France, Canada, Japan), this should apply to a large number of models. We see that

$$S_t = \frac{P_t^*}{P_t} \frac{\exp nr_{t,n}^*}{\exp nr_{t,n}} \frac{Q E_t \left(z_{t,n} \cdot 1 \cdot \frac{Q_{t+n}}{Q} \right)}{E_t(z_{t,n})}. \tag{7}$$

Taking logs of both sides,

$$s_t = p_t - p_t^* + n\left(r_{t,n}^* - r_{t,n}\right) + q - \vartheta_t, \tag{8}$$

where θ_t is given by

$$\exp -\vartheta_t = \frac{E_t \left(z_{t,n} \cdot 1 \cdot \frac{Q_{t+n}}{Q} \right)}{E_t(z_{t,n})}. \tag{9}$$

Although not necessary for what follows, we gain additional insight by looking at the log-normal case in which we have equation (10).

$$-\vartheta_t = \mathrm{cov}_{t,n}(\ln z_{t,n}, q_{t+n} - q) + \mathrm{var}_{t,n}(q_{t+n} - q) + E_t(q_{t+n} - q) \tag{10}$$

We note that the first term in the above expression is the conditional covariance between the stochastic discount factor and real exchange rate that prevails when the zero-coupon inflation-linked bonds mature. This can be interpreted as a risk premium that opens up a wedge between known real return (to a U.S. investor) of holding a long-maturity Treasury inflation-protected security (TIPS) and the stochastic real return to a U.S. investor of holding a UK linker. When this covariance is negative, an unhedged position in a UK linker pays off less (because of realized real appreciation of dollar relative to the pound) when the stochastic discount factor is high. Thus a *negative theta* corresponds to a *positive risk premium on the UK linker*. That is, the known real return on the U.S. linker is less than the expected real return to the U.S. investor, inclusive of expected appreciation of the pound, of holding a UK linker when θ is positive. An increase in the expected excess return on the UK linker will require some combination of an increase in r_t^* and a jump in appreciation of the dollar. Below we study the empirical covariance between the observed θ_t and the inflation-indexed interest differential to quantify how much of premium shocks is reflected in linker yields and how much is reflected in the exchange rate.

Even for a risk-neutral investor, θ_t will be non-zero as it reflects the conditional variance of the long-horizon forecast of the log level of the real exchange rate. θ_t will also be non-zero if the expected deviation from relative purchasing power parity (PPP) persists beyond n (in our case, ten) years. However, in what follows we shall assume for ease of exposition that expected deviations from PPP at a ten-year horizon are sufficiently close to zero so as to be ignored. Importantly, however, researchers who have a view on long-horizon PPP deviations can include that view directly and use it as an input to the accounting framework we develop below. Thus, in what follows, we shall refer to θ_t as the risk premium.

We define the *risk-neutral fair value (RNFV)* of the exchange rate by

$$\tilde{S}_t = \frac{P_t^*}{P_t}\frac{\exp nr_{t,n}^*}{\exp nr_{t,n}}Q \tag{11}$$

or in log terms,

$$\tilde{s}_t = p_t - p_t^* + n\big(r_{t,n}^* - r_{t,n}\big) + q. \tag{12}$$

It is important to realize what *is not* required for this approach to account for nominal exchange rate movements. We do not require that the expectations hypothesis of the term structure hold for home and foreign yield curves, either inflation indexed or nominal. We do not require a time-series model for inflation or the short-term interest rate to make inferences about long-term real interest rates.

It is worth noting that the complete-markets assumption would put a number of additional restrictions on the joint behavior of exchange rates and bond yields, both inflation indexed and nominal. For example, under complete markets, Backus, Foresi, and Telmer (2001) show that

$$\frac{S_{t+1}}{S_t} = \frac{m_{t,1}}{m_{t,1}^*}. \tag{13}$$

We see that in our notation this would also imply

$$\frac{Q_{t+1}}{Q_t} = \frac{z_{t,1}}{z_{t,1}^*}.$$

These are elegant, powerful implications, but we do not impose them on the data or use them to interpret real-time exchange rate fluctuations.

Fama (1984) is the classic study of the risk premium to holding a long position in a foreign currency for one period (but also see Clarida, Davis, and Pedersen 2009 for a recent analysis of what can—and can't—be learned from a Fama regression):

$$rp_{t,1} = E_t s_{t+1} - s_t + i_{t,1}^* - i_{t,1}, \tag{14}$$

where lowercase i denotes the short-term nominal interest rate. How is the Fama risk premium related to θ_t? For sake of illustration, consider a short holding period and assume that expected inflation differentials over that holding period are zero. Then we have (15):

$$\begin{aligned} rp_{t,1} &= nE_t\left(r^*_{t+1,n} - r^*_{t,n}\right) - nE_t(r_{t+1,n} - r_{t,n}) \\ &\quad + \vartheta_t - {}_t\vartheta_{t+1} + \left(i^*_{t,1} - i_{t,1}\right). \end{aligned} \tag{15}$$

Thus the Fama premium comprises three terms. First, there is the forecastable change in foreign relative to home inflation-indexed constant-maturity bond yields. Second, there is the forecastable change in the expected excess U.S. dollar return to investing in a long-maturity UK linker relative to a U.S. linker. Third, there is the short-term nominal interest rate differential in favor of the foreign country. Under risk neutrality we would have

$$nE_t\left(r^*_{t+1,n} - r^*_{t,n}\right) - nE_t(r_{t+1,n} - r_{t,n}) = \left(i_{t,1} - i^*_{t,1}\right).$$

This makes sense. In the absence of an expected inflation differential and a risk premium, uncovered interest parity requires the dollar to depreciate in expectation at rate $i_{t,1} - i^*_{t,1}$. This can only happen if there is a forecastable increase in foreign long-maturity inflation-indexed bond yields relative to home inflation-indexed bond yields. More generally, we have (16):

$$\begin{aligned} rp_{t,1} &= nE_t\left\{\left(r^*_{t+1,n} - r^*_{t,n}\right) - (r_{t+1,n} - r_{t,n})\right\} \\ &\quad + \vartheta_t - {}_t\vartheta_{t+1} + \left(i^*_{t,1} - i_{t,1}\right) + {}_t\pi^d_{t,1}, \end{aligned} \tag{16}$$

where ${}_t\pi^d_{t,1} = E_t(\pi_{t,1} - \pi^*_{t,1})$ is the expected inflation differential over one period.

We note that the *level* of the Fama premium on a one-period nominal pound investment is related to the *change* in the risk premium on an n period inflation-indexed pound investment.

3. Comparison with the Literature

There is of course a long and proud tradition in the international finance literature, beginning with Frankel (1979), of empirically relating real exchange rates to real interest differentials (Shafer and Loopesko 1983 and Campbell and Clarida 1987 are early examples).

For the most part, this literature pre-dates the widespread introduction of long-maturity inflation-indexed bonds and of necessity solves forward the real version of the deviations from the uncovered interest rate parity equation.

$$rp_{t,1} = E_t q_{t+1} - q_t + er^*_{t,1} - er_{t,1},$$

where $er_{t,1} = i_{t,1} - E_t \pi_{t,1}$ is the ex ante short-term real interest rate at home and similarly abroad. Solving forward and assuming q_t is strictly stationary, we obtain the following (see Engel 2010 for a lucid discussion and Brunermeier, Nagel, and Pedersen 2009 for an interpretation of the forward solution for the nominal exchange rate under uncovered interest parity):

$$q_t = \sum\nolimits_{i=0}^{\infty} \left({}_t er^*_{t+i,1} - {}_t er_{t+i,1} - \mu\right) - \sum\nolimits_{i=0}^{\infty} ({}_t rp_{t+i,1} - \lambda) + q. \tag{17}$$

Note that convergence of these non-discounted present-value equations requires the unconditional mean of the ex ante real rate differential μ to equal the mean of the Fama risk premium λ. Comparing terms, we must have

$$\sum\nolimits_{i=n}^{\infty} \left({}_t er^*_{t+i,1} - {}_t er_{t+i,1} - \mu\right) - \sum\nolimits_{i=0}^{\infty} ({}_t rp_{t+i,1} - \lambda) \\ = n\left(r^*_{t,n} - r_{t,n}\right) - \vartheta t.$$

For concreteness, suppose that

$$\sum\nolimits_{i=n}^{\infty} \left({}_t er^*_{t+i,1} - {}_t er_{t+i,1} - \mu\right) = 0$$

and similarly for the Fama premium after n periods. We then obtain an equation (18) relating the observed long-maturity inflation-indexed yield differential to the present value of ex ante (un-indexed) real short-term interest rates differentials and the present value of the Fama risk premiums,

$$n\left(r^*_{t,n} - r_{t,n}\right) = \sum\nolimits_{i=0}^{n} \left({}_t er^*_{t+i,1} - {}_t er_{t+i,1}\right) + \theta_t - \sum\nolimits_{i=0}^{n} {}_t rp_{t+i,1}. \tag{18}$$

Thus the observed difference between known UK and U.S. linker yields is equal to (i) the sum of ex ante short-term un-indexed real rate differentials plus (ii) the risk premium on long-maturity UK linkers relative to U.S. linkers minus (iii) the sum of expected one-period Fama risk premiums on unhedged nominal pound investments.

There are two approaches that have been used to turn (17) into a model of exchange rates and real interest rates. Campbell and Clarida (1987), Clarida and Galí (1994), and, recently, Engel (2010) estimate time-series models of ex ante short-term real rate differentials and use a vector autoregression to forecast the infinite sum of ex ante real differentials. Of course, the reliability of this approach depends on the linear time-series models being a good proxy for expected future ex ante real interest rates. An alternative approach (Shafer and Loopesko 1983) relies on the expectations hypothesis of the term structure to substitute out for the ex ante nominal short rate differentials and to rely on surveys or time-series models of inflation to recover an estimate of long-term ex ante real rate differentials.

$$n\left(I^*_{t,n} - I_{t,n}\right) = \sum\nolimits_{i=0}^{n} \left({}_t er^*_{t+i,1} - {}_t er_{t+i,1}\right) + tp_n + \sum\nolimits_{i=0}^{n} \left({}_t \pi^*_{t+i,1} - {}_t \pi_{t+i,1}\right)$$

Note that for this approach to work, not only must a model of inflation expectations be estimated, but one must also assume a constant term premium. An advantage of our approach outlined above is that, under the rather modest assumption that the pricing kernel is homogeneous in price levels, we can use observation on inflation-indexed bond yields directly to recover the risk-neutral fair value of nominal exchange rates as well as econometric free estimates of the risk premium relevant for pricing inflation-indexed yield curves and currencies.

4. Data

Our data set comprises daily observations on spot exchange rates, inflation-indexed bond yields, and monthly observations on consumer price indexes for the United States, United Kingdom, and euro area for the period January 2001 through January 2011 and for Japan since January 2005, shortly after inflation-indexed bonds were introduced. We convert monthly CPI levels to daily observations via interpolation. Given the low and relatively stable rate of inflation for these countries over this period, the results are not sensitive to the method of interpolation. This is because we model the *level* of the risk-neutral fair value of the nominal exchange rate as a function of the levels of the U.S. and foreign CPI so that any intramonth measurement error introduced via interpolation of the monthly CPI data will be negligible relative to the variance in observed inflation-linked bond yields or the nominal exchange rate itself.

Our theoretical model is derived in terms of the yields on inflation-indexed zero-coupon bonds. Inflation-indexed bonds are typically issued in coupon form. However, in the United States there is a market in which inflation-indexed coupon TIPS are stripped of their coupons and trade in zero-coupon form. In our empirical analysis, we will use daily data on constant ten-years-to-maturity yields on zero-coupon TIPS provided by Barclays. In the other countries in our study, zero-coupon linkers do not trade actively and, for the bulk of our study, we will use the data from Barclays that are available for coupon-bearing inflation-indexed bonds with ten years to maturity.

One final point to discuss is how we calibrate the constant term in equation (7) for risk-neutral fair value. This constant term is not important for much of what we do since we will often seek to account for *changes* in observed nominal exchange rates in terms of *changes* in fair value and changes in the risk premium. For these exercises, the constant drops out. However, in drawing some of the graphs, we will wish to preserve the levels information and will select the constant term based upon the average real exchange rate during the sample adjusted by a subjective assessment of the extent to which the average real exchange rate during the sample over- or underestimated the true value of the constant term.

5. Empirical Results

We now use the framework developed above to interpret the behavior of the euro, pound, and yen exchange rates over the past ten years. There are no econometric estimates to present because our framework (equation (7)) provides day by day a real-time decomposition of the change in the exchange into the change in the risk-neutral fair value and the change in risk premium. Our framework allows—indeed we expect to find—periods in which shocks to the risk premium are large and die out slowly, while there may be other periods in which exchange rate movements, contrary to the original Meese-Rogoff (1983) finding that exchange rate changes are difficult to explain even given ex post realizations of fundamentals, are well accounted for by shifts in our measure of risk-neutral fair value derived above.

We present our main findings in a series of figures. For each exchange rate, the figures will help us to identify as well as quantify the importance of shocks to fair value and shocks to the risk premiums in accounting for exchange rate fluctuations over different periods as well as over various horizons of interest. As our sample includes the global financial crisis and its aftermath (at least through January 2011), we are particularly interested in determining and quantifying the shifts in risk premium and risk-neutral fair value that occurred over this period. Recall in our framework, period by period we have

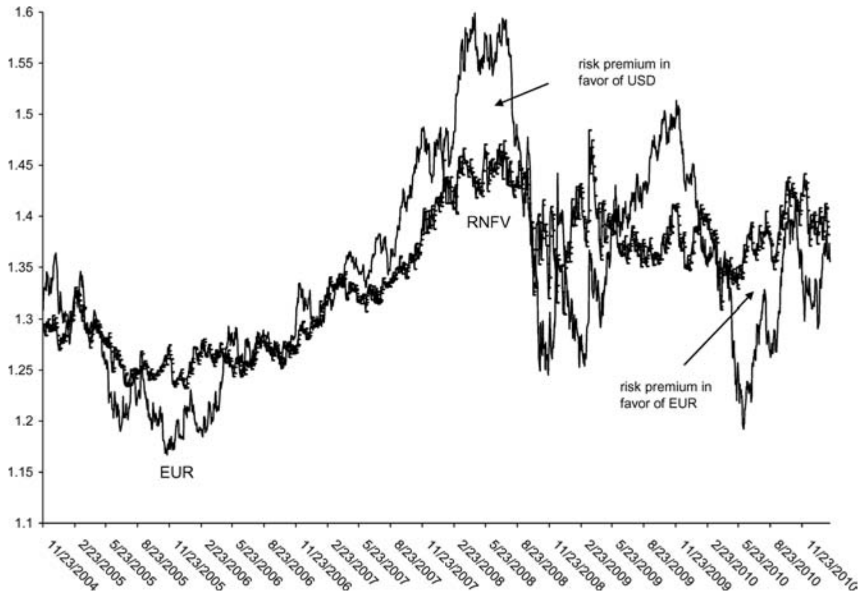
$$s_t = p_t - p_t^* + n\left(r_{t,n}^* - r_{t,n}\right) + q - \vartheta_t.$$

A positive shock to θ_t is an increase in the risk premium on a UK investment which increases the expected excess return a U.S. investor earns on a UK investment. This must be brought about by some combination of *a rise in UK–U.S. real interest differential and/or an appreciation of the dollar relative to the pound.* A period in which $\theta > 0$ (risk premium in favor of the pound) is a period in which the pound is weaker than risk-neutral fair value. A period in which $\theta < 0$ (risk premium in favor of the dollar) is a period in which the pound is stronger than risk-neutral fair value.

5.1 Euro

In figure 1—and in figures 3, 5, and 7 as well—the thin solid line depicts the spot exchange rate, in this case the U.S. dollar price of a euro; the thicker dotted line is the risk-neutral fair value (RNFV) defined by equation (11). The amount by which the exchange rate EUR exceeds RNFV measures the risk premium *in favor of the USD*

Figure 1. Decomposition of EUR 2004–10

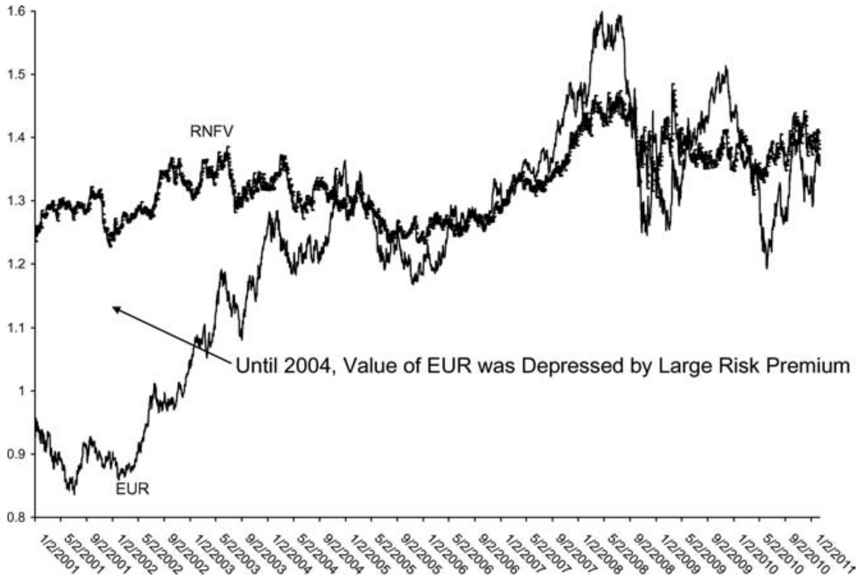


that is reflected in the EUR spot exchange rate. This corresponds to $-\theta_t$. The amount by which the exchange rate EUR falls short of RNFV measures the risk premium *in favor of the EUR* that is reflected in the EUR spot exchange rate. This corresponds to θ_t.

Our framework, we believe, provides a compelling qualitative as well as a plausible quantitative account of the swings in euro exchange rate since 2005. As can be seen from the figure, the broad move in the euro from 1.25 in the summer of 2005 to 1.45 in the spring of 2008 is well accounted for, both in direction and in magnitude, by the rise in the risk-neutral fair value during that period. According to our model, the next move in the euro from 1.45 to the "brutal" level of 1.60 reached in the summer of 2008 was due almost entirely to an equal move in the risk premium, in favor of the dollar and thus against the euro. Figure 2 illustrates that the weakness of the euro relative to the dollar before 2004 is attributed to a significant risk premium which investors required to hold euro assets in its early years.

Since the onset of the global financial crisis in September 2008, movements in the euro have been dominated by fluctuations in risk

Figure 2. Decomposition of EUR 2001–11

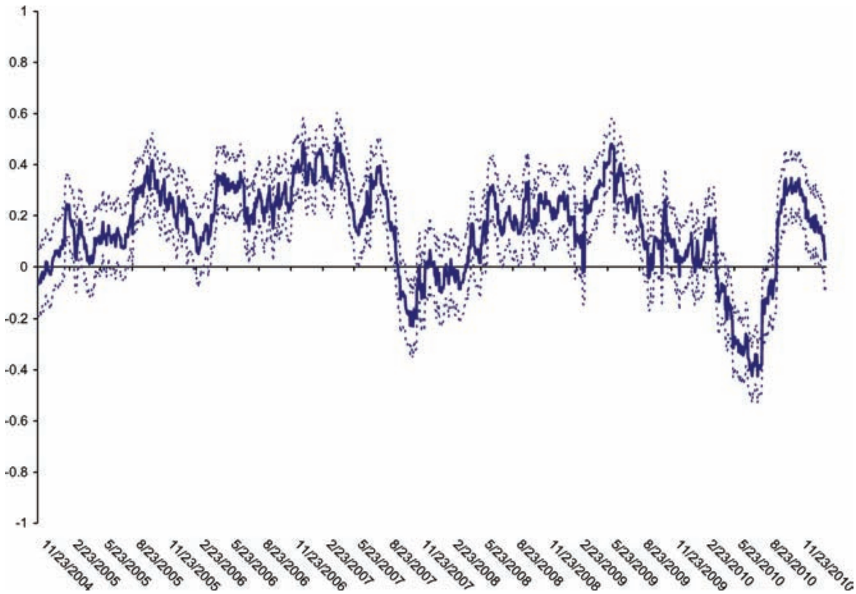


premium with risk-neutral fair value fluctuating in a rather narrow range centered at roughly 1.37. In October 2008, our measure of the risk premium swings in favor of the euro (e.g., it appreciated the dollar price of the euro to such an extent that it set up the expectation of a depreciation and thus capital gain on a euro investment). The risk premium swings back in favor of the dollar in the second half of 2009 as the dollar depreciates in tandem with the Federal Reserve's quantitative easing programs announced in March of that year. Since 2010, our framework indicates that the foreign exchange market has required a positive risk premium to hold the euro. This period, of course, coincides with the crisis in the euro periphery.

Of course, it is important to confirm that the visual impression conveyed by the figure is evident in the actual empirical correlation between the euro exchange rate and our measure of risk-neutral fair value.

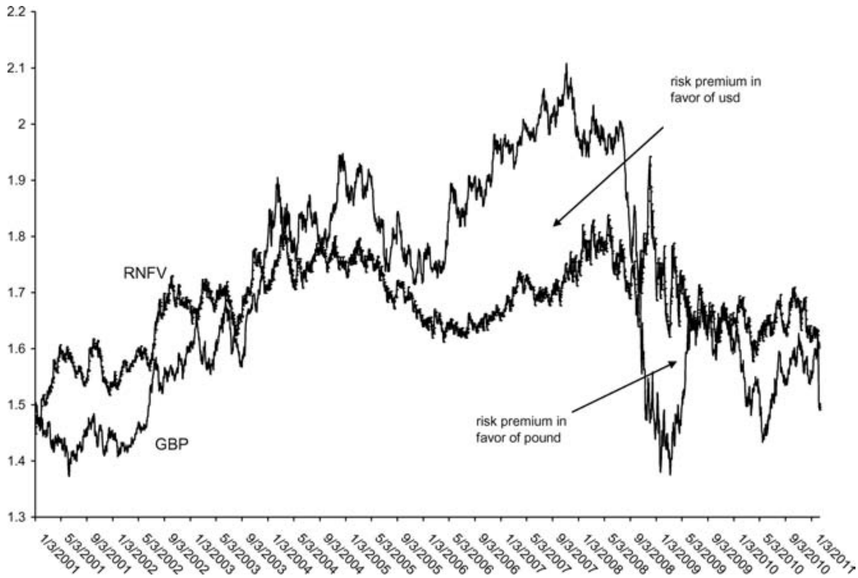
Figure 3 depicts the correlation (over rolling sixty-day windows) between daily changes in euro exchange rates and daily changes in our measure of risk-neutral fair value which, of course, is dominated by daily changes in real interest rate differentials between European

Figure 3. Correlation between Daily Changes in EUR and Daily Changes in RNFV: Sixty-Day Window + and − One-Standard-Error Bands



and U.S. inflation-indexed bonds. We see that periods in which the correlation is in the range of 0.3 to 0.4 are not uncommon. We also see that in periods in which shocks to the risk premium are seen to dominate, the correlation between the euro and RNFV falls to zero or is even negative. One is tempted to identify periods in which the exchange rate is well accounted for by movements in RNFV (such as 2005 to 2008 in figure 1) as periods in which "fundamentals" mostly matter for exchange rate determination, in contrast to periods since September 2008 in which "fundamentals" are pushed aside and "risk aversion" appears to take over. But within the strict logic of our framework, this temptation would not be justified. Fundamentals may drive the risk premium as well, but without imposing much more additional structure on $m_{t,n}$, we can't really say more. However, unlike the traditional approach (Fama 1984) in which an unobserved currency risk premium must be inferred by extracting the forecastable component from realized returns on currency carry

Figure 4. Decomposition of GBP



trades, our framework provides an econometric free measure of the relevant risk premium given observed yields on inflation-indexed bonds and the spot exchange rate.

5.2 Pound

Figure 4 depicts our decomposition of the GBP exchange rate into its risk-neutral fair value and risk premium components. From 2001 through summer of 2005, the appreciation of the pound from 1.50 to 1.75 is almost fully accounted for by an equal rise in our estimate of risk-neutral fair value from the inflation-indexed bond market. However, our framework accounts for the subsequent move up from 1.75 to 2.05 reached in January 2008 almost entirely by the emergence of a substantial risk premium in favor of the dollar (i.e., a risk premium that set up expectation of a higher return on U.S. inflation-linked bonds). This risk premium is eliminated and shifts in favor of the GBP in September 2008 and has remained in place since. Since 2009, our estimate of *risk-neutral fair value* has stayed in a narrow range centered around 1.65.

Figure 5. Correlation between Daily Change in GBP and Daily Change in RNFV: Sixty-Day Window

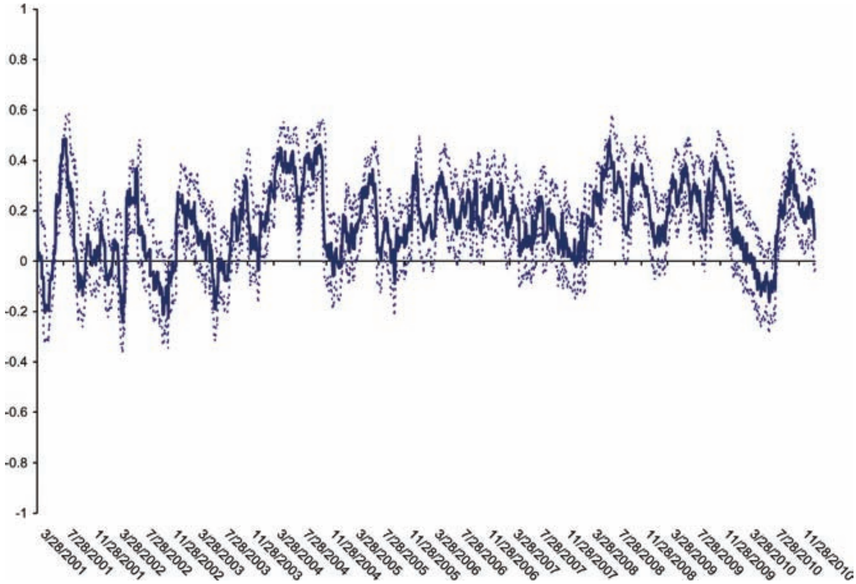
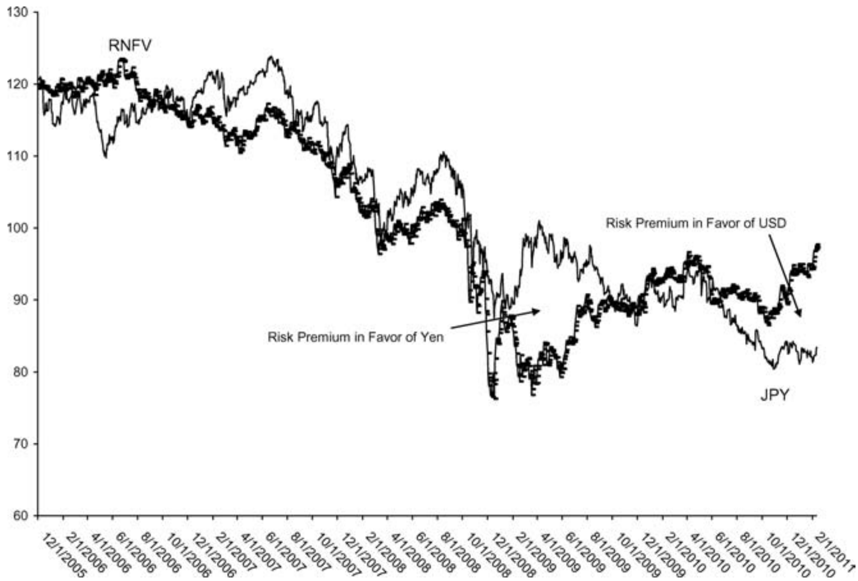


Figure 5 depicts the correlation (over rolling sixty-day windows) between daily changes in GBP exchange rates and daily changes in our measure of risk-neutral fair value. Again we see that periods in which the correlation between daily changes is in the range of 0.3 to 0.5 are not uncommon. We also see that in periods in which shocks to the risk premium are seen to dominate, the correlation between the GBP and RNFV falls to zero or is even negative. This implies that large shocks to the risk premium in favor of the pound (or, in figure 1, the euro) tend to require both depreciations of the exchange rate relative to the dollar—to set up the expectation of future appreciation—and a rise in the real interest rate differential in favor of the pound (or the euro).

5.3 Yen

Figure 6 depicts our decomposition of the JPY exchange rate into its risk-neutral fair value and risk premium components. From 2005 through the summer of 2010, the appreciation of the yen from 120

Figure 6. Decomposition of JPY



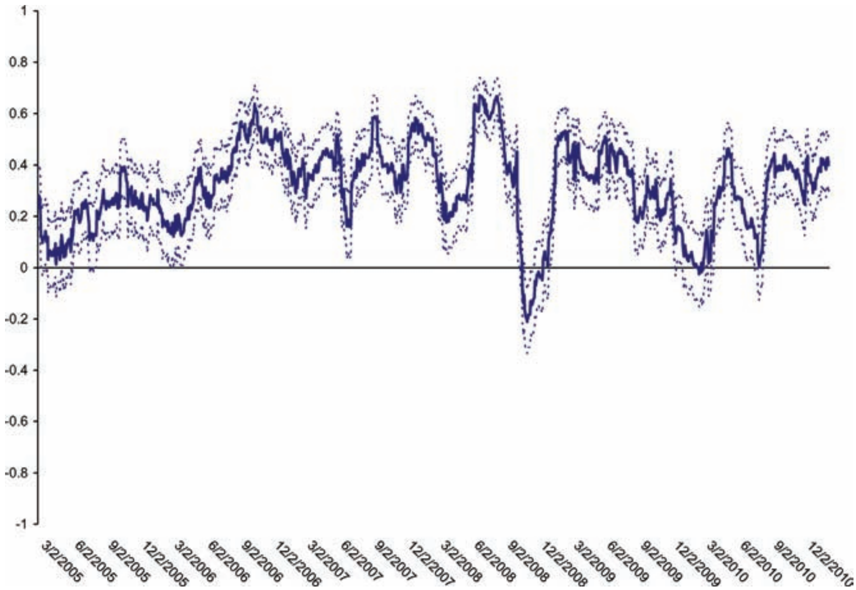
to 88 is almost fully accounted for by an equal shift in our estimate of risk-neutral fair value.

During most of this period there was also a modest and not very volatile risk premium in favor of the yen. This risk premium widened in the fall of 2008 but was almost entirely eliminated by the summer of 2009. Since that time, we estimate that a risk premium in favor of the dollar opened up as the yen continued to appreciate notwithstanding a shift in risk-neutral fair value in the direction of a weaker yen. Our last data point is February 11, 2011. Finally, figure 7 confirms that, if anything, changes in the yen and our measure of risk-neutral fair value have been more highly correlated than we found for the euro and the pound.

6. Concluding Remarks

This paper has derived a novel structural relationship between the nominal exchange rate, national price levels, and observed yields on long-maturity inflation-indexed bonds. This relationship can be interpreted as defining the risk-neutral fair value of the exchange

Figure 7. Correlation of Daily Changes in JPY and RNFV: Sixty-Day Window



rate as well as an empirically observable measure of the risk premium that can open up a wedge between the observed level of the nominal exchange rate and its risk-neutral fair value. We take our theory to the data to study high-frequency, real-time decompositions of pound, euro, and yen exchange rates into their risk-neutral fair value and risk premium components and find that the relative importance of these two factors varies depended on the subsample studied. However, subsamples in which, contrary to the Meese-Rogoff (1983) puzzle, 30 to 60 percent of the fluctuations in daily exchange rate changes are explained by contemporaneous changes in risk-neutral fair value are not uncommon.

A priority for future research is to explore the macroeconomic and financial factors that might plausibly account for the observed movements in the risk premium term defined by equation (9). We think it is important that our framework points to a general equilibrium relationship between the risk premium embedded in the level of the exchange rate and the inflation risk premium on nominal zero-coupon bonds compared with inflation-linked bonds. Whereas the exchange rate risk premium defined by equation (9) reflects the covariance between the real stochastic discount factor $z_{t,n}$ and cumulative real exchange rate depreciation until maturity, the risk premium on nominal bonds compared with inflation-indexed bonds reflects the covariance between the real stochastic discount factor $z_{t,n}$ and cumulative inflation until maturity.

Appendix

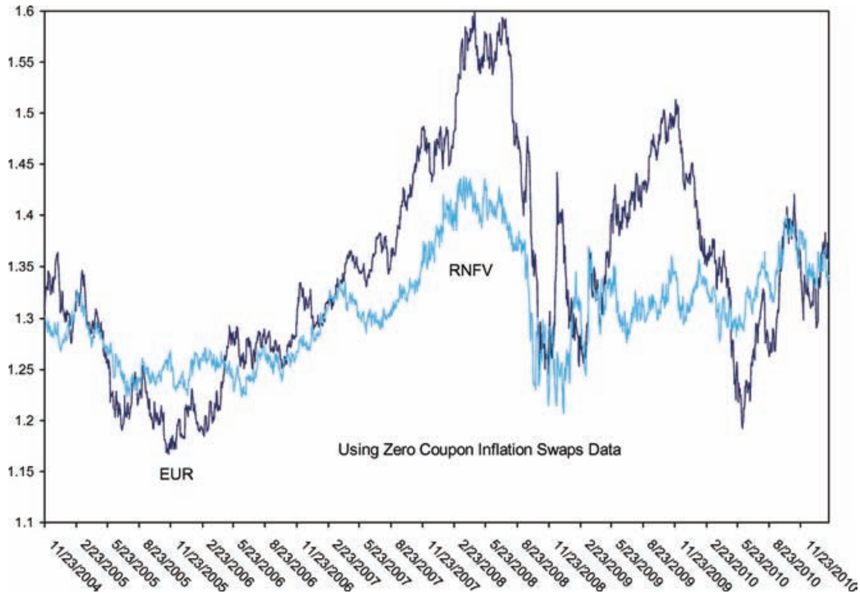
We recognize that using the available data on inflation-indexed coupon bond yields could potentially introduce a specification error in that these yields are in general not identical to the unobserved yields on similar, but zero-coupon, instruments priced in equations (3) and (5). In Europe and the United Kingdom, while zero-coupon inflation-linked bonds do not trade actively, there is a deep market in zero-coupon inflation swaps. We show now that a zero-coupon inflation swap plus a cash investment in a zero-coupon nominal government bond can, under certain assumptions, replicate the cash flow of a zero-coupon linker. We show that all of our main findings are robust when we use data on derived zero-coupon real yields from zero-coupon inflation swap data for the United Kingdom and euro area where they are available.

Recall that the nominal payoff in n years of a zero-coupon bond with par value of one dollar is just $1 \cdot (P_{t+n}/P_t)$ dollars. To obtain this bond, the investor must pay a price today of ρ_t dollars. Consider as an alternative entering into a zero-coupon inflation swap with a counterparty to receive realized cumulative inflation in n years and to pay the counterparty $(1+\pi^s)^n - 1$. Here π^s is the fixed rate agreed up front on the inflation swap. Thus the cash flow from the swap in n years is

$$\textit{cash flow from inflation swap}_{t+n} = 1 \cdot \{(P_{t+n}/P_t) - 1\} - 1 \cdot \{(1+\pi^s)^n - 1\}.$$

Now, at time t, also purchase a zero-coupon nominal bond with par value of $1 + \cdot\{(1+\pi^s)^n - 1\}$. It is easy to see that the combined cash

Figure 8. Decomposition of EUR Using Inflation Swaps Data



flow in n years from the nominal bond and inflation swap exactly replicates the cash flow from the zero-coupon linker:

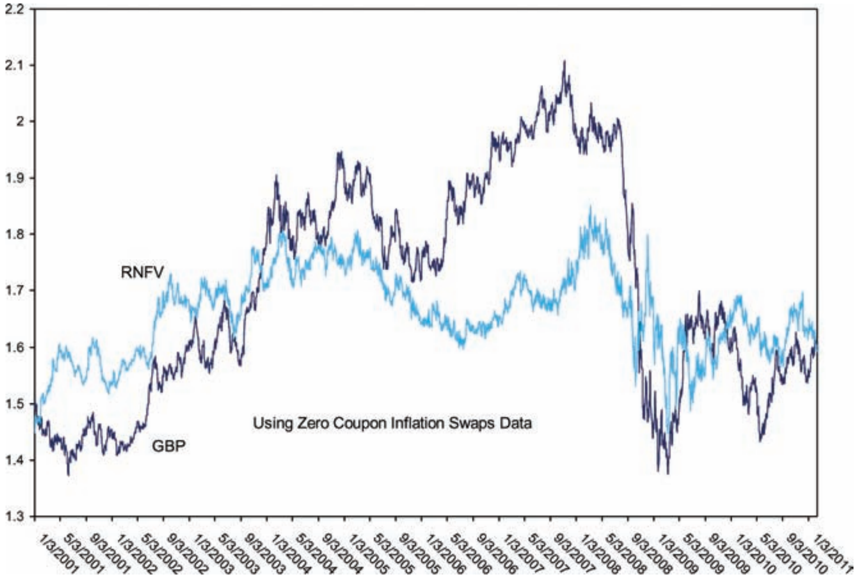
$$\begin{aligned}&\textit{zero-coupon nominal bond} + \textit{inflation swap}\\ &\qquad = \textit{zero-coupon inflation-linked bond}.\end{aligned}$$

What is the price today of securing this state contingent cash flow? Simply $(1 + \pi^s)^n \rho_t^n$, where ρ^n is the price of a nominal zero-coupon bond with par value of one dollar. Thus we must have

$$\exp -nr_{t,n} = (1 + \pi^s)^n \rho_t^n.$$

Thus, in theory, the existence of an inflation swaps market and a zero-coupon nominal bond market makes a zero-coupon inflation-linked market redundant. We can use the implied zero-coupon inflation-linked bond yields from the inflation swaps market as a robustness check on the results reported in the text that are based on the yields of the inflation-linked coupon bonds that are traded

Figure 9. Decomposition of GBP Using Inflation Swaps Data



in the United Kingdom and Europe. As figures 8 and 9 make clear, our main results do in fact appear to be robust to this choice.

References

Backus, D., S. Foresi, and C. Telmer. 2001. "Affine Term Structure Models and the Forward Premium Anomaly." *Journal of Finance* 56 (1): 247–77.

Brunermeier, M., S. Nagel, and L. Pedersen. 2009. "Carry Trades and Currency Crashes." In *NBER Macroeconomics Annual 2008*, ed. D. Acemoglu, K. Rogoff, and M. Woodford, 313–47. Cambridge, MA: MIT Press.

Campbell, J., and R. Clarida. 1987. "The Dollar and Real Interest Rates." *Carnegie-Rochester Conference Series on Public Policy* 27 (1): 103–39.

Clarida, R., J. Davis, and N. Pedersen. 2009. "Currency Carry Trade Regimes: Beyond the Fama Regression." *Journal of International Money and Finance* 28 (8): 1375–89.

Clarida, R., and J. Galí. 1994. "Sources of Real Exchange-Rate Fluctuations: How Important are Nominal Shocks?" *Carnegie-Rochester Conference Series on Public Policy* 41 (1): 1–56.

Engel, C. 2010. "The Real Exchange Rate, Real Interest Rates, and the Risk Premium." Mimeo (December).

Fama, E. 1984. "Forward and Spot Exchange Rates." *Journal of Monetary Economics* 14 (3): 319–38.

Frankel, J. 1979. "On The Mark: A Theory of Floating Exchange Rates Based on Real Interest Differentials." *American Economic Review* 69 (4): 601–22.

Lucas, R. 1982. "Interest Rates and Currency Prices in a Two-Country World." *Journal of Monetary Economics* 10 (3): 335–59.

Meese, R., and K. Rogoff. 1983. "Empirical Exchange Rate Models of the Seventies: Do They Fit Out of Sample?" *Journal of International Economics* 14 (1–2): 3–24.

Shafer, J., and B. Loopesko. 1983. "Floating Exchange Rates after Ten Years." *Brookings Papers on Economic Activity* 14 (1): 1–86.