Get Real: Interpreting Nominal Exchange Rate Fluctuations

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I. 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 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 dataset 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 sub sample studied. However, sub samples 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.

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II. 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 (US dollar) price today of an asset that delivers a random dollar cash flow at some date in future (for concreteness , 10 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

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

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}

2) $m_{t,n} = z_{t,n}\dfrac{P_t}{P_{t+n}}$

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 1 dollar in n years multiplied by cumulative realized inflation over the next n years.

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

Or, dividing by ρ_t

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

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

US investors can also obtain US 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

5) $$S_t \rho^*_t = E_t(m_{t,n} \cdot 1 \cdot S_{t+n} \cdot \frac{P^*_{t+n}}{P^*_t})$$

Or dividing though:

6) $$1 = \exp nr^*_{t,n}\, E_t(z_{t,n} \cdot 1 \cdot \frac{Q_{t+n}}{Q_t})$$

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 (US, UK, France, Canada, Japan) this should apply to a large number of models. We see that

$$7)\quad S_t = \frac{P^*_t}{P_t}\frac{\exp nr^*_{t,n}}{\exp nr_{t,n}}\frac{QE_t(z_{t,n}\cdot 1\cdot \frac{Q_{t+n}}{Q})}{E_t(z_{t,n})}$$

Taking logs of both sides

$$8)\quad s_t = p_t - p^*_t + n(r^*_{t,n} - r_{t,n}) + q - \vartheta_t$$

Where θ_t is given by

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

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

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

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 US investor) of holding a long maturity TIP and the stochastic real return to a US 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 US linker is less than the expected real return to the US 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 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 PPP persists beyond n (in our case, 10) years. However in what follows we shall assume for ease of exposition that expected deviations from PPP at a 10 years 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

11) $$\tilde{S}_t = \frac{P^*_t}{P_t}\frac{\exp nr^*_{t,n}}{\exp nr_{t,n}}Q$$

or in log terms

12) $$\tilde{s}_t = p_t - p^*_t + n(r^*_{t,n} - r_{t,n}) + q$$

It is important to realize the 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 et. al. (2001) show that

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

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 Clarida, Davis, and Pedersen (2009) for a recent analysis of what can – and can't be leaned – from a Fama regression):

14) $$rp_{t,1} = E_t s_{t+1} - s_t + i^*_{t,1} - i_{t,1}$$

where lower case 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)

15) $$rp_{t,1} = nE_t(r^*_{t+1,n} - r^*_{t,n}) - nE_t(r_{t+1,n} - r_{t,n}) + \vartheta_t - {}_t\vartheta_{t+1} + (i^*_{t,1} - i_{t,1})$$

Thus the Fama premium is comprised of 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 US dollar return to investing in a long maturity UK linker relative to a US linker. Third there is the short term nominal interest rate differential in favor of the foreign country. Under risk neutrality we would have

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

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)

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

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.*

III. ***Comparison with the Literature***

There is of course a long and proud tradition in the international finance literature, beginning with Frankel (1978), 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 UIP 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 (see Engle (2010) for a lucid discussion and Brunermeier, Nagel, and Pedersen (2008) for an interpretation of the forward solution for the nominal exchange rate under uncovered interest parity):

$$17)\quad q_t = \sum_{i=0}^{\infty}({}_t er^*_{t+i,1} - {}_t er_{t+i,1} - \mu) - \sum_{i=0}^{\infty}({}_t rp_{t+i,1} - \lambda) + q$$

Note that convergence of these non discounted present value equation 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

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

For concreteness suppose that

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

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

$$18) \quad n(r^*_{t,n} - r_{t,n}) = \sum_{i=0}^{n} ({}_t er^*_{t+i,1} - {}_t er_{t+i,1}) + \theta_t - \sum_{i=0}^{n} {}_t rp_{t+i,1}$$

Thus the observed difference between known UK and US linker yields is equal to the 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 US 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 Gali (1994) and recently Engel (2010) estimate time series models of ex ante short term real rate differentials and use a vector auto regression 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.

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

Note that for this approach to work, not only must a model of inflation expectations be estimated, but one must 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.

IV. Data

Our data set is comprised of daily observations on spot exchange rates, inflation indexed bond yields, and monthly observations on consumer price indexes for the US, UK, and Euro area for the period January 2001 though 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 relative 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 US and foreign CPI so that any intra - month 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 US 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 10 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 10 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 the 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 under estimated the true value of the constant term.

V. Empirical Results

We now use the framework developed above to interpret the behavior of the Euro, Pound, and Yen exchange rates over the past 10 years. There are no econometric estimates to present because our framework (Equation 7) provides day by day a real time decomposition 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 even ex post realizations of fundamentals, are well accounted for by shifts in our measure of risk neutral fair value derived above.

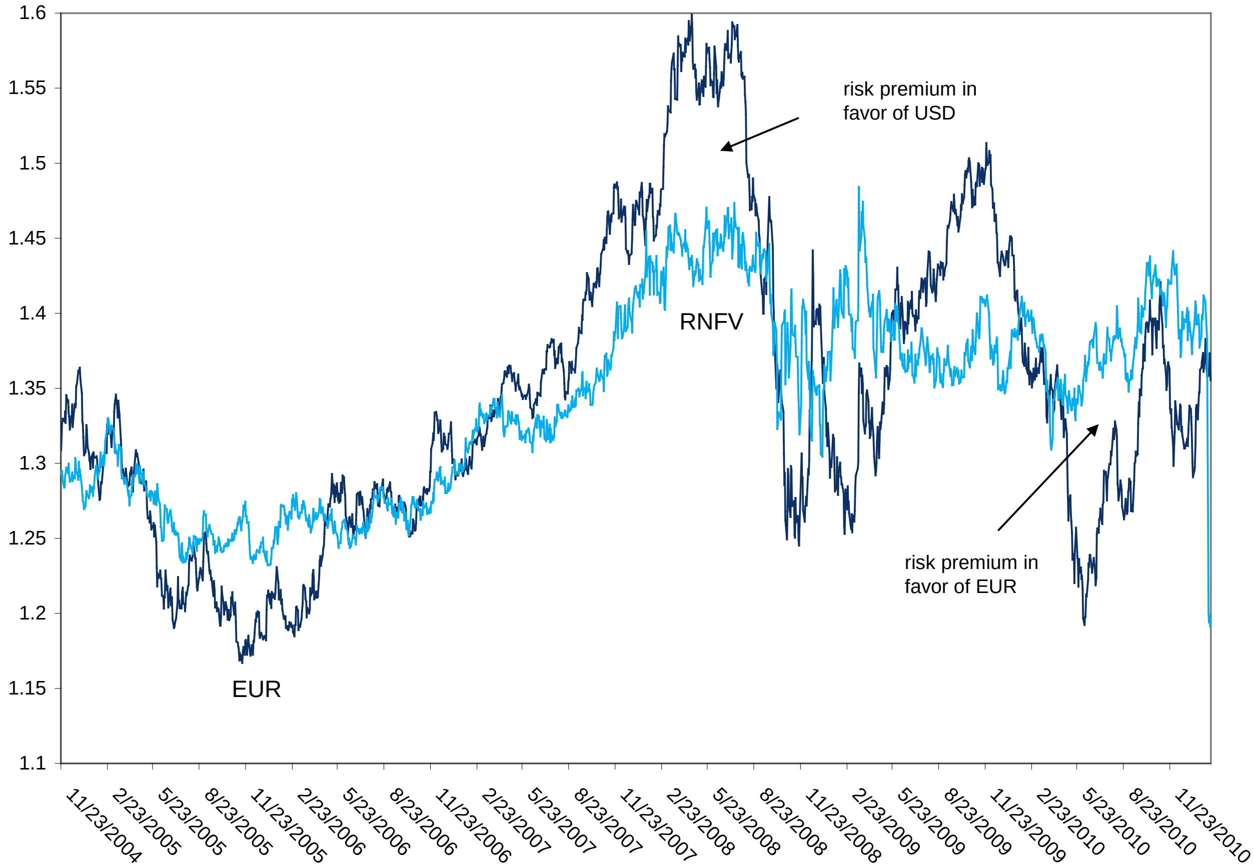
We present our main findings in a series of charts. For each exchange rate, the charts will help us to identify as well as quantify the importance of shocks to fair value and shocks to the risk premiums in accounting for exchange rate fluctuations over different periods as well as over various horizons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

$$s_t = p_t - p^*_t + n(r^*_{t,n} - r_{t,n}) + q - \vartheta_t$$

A positive shock to θ_t is an increase in the risk premium on a UK investment which increases the expected excess return a US investor earns on a UK investment. This must be brought about by some combination of *a rise in UK – US 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 dollar) is a period in which the pound is stronger than risk neutral fair value.

Euro

Chart 1



In Chart 1, and in all subsequent charts, the dark blue line depicts the spot exchange rate, in this case the US dollar price of a Euro, the aqua – blue 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* 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 chart, 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 an equal move in the risk premium, in favor of the dollar and thus against the Euro.

Since the onset the global financial crisis in September 2008, movements in the Euro have been dominated by fluctuations in risk 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 it set up the expectation of a deprecation 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 Fed'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 the crisis in the Euro periphery.

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

Chart 2

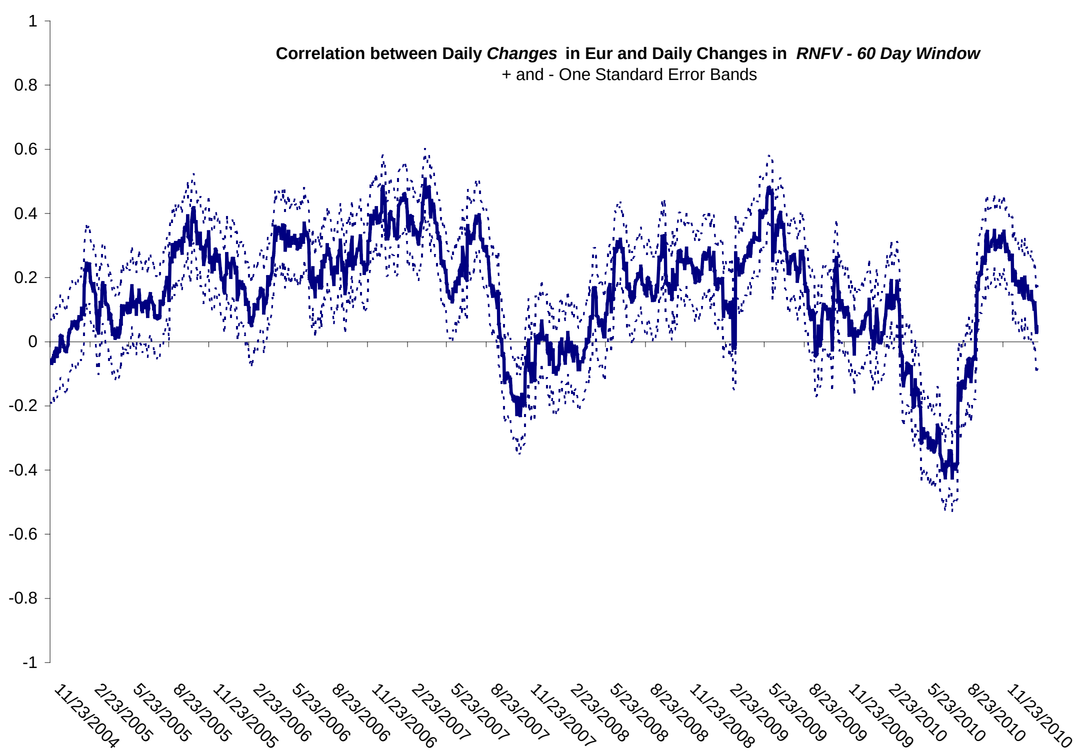
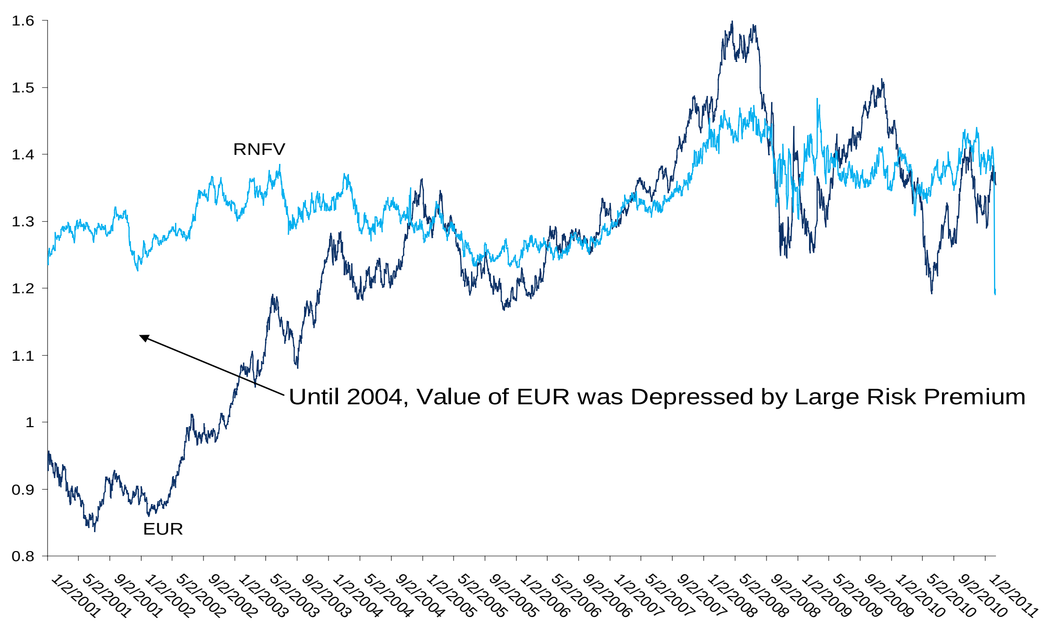


Chart 2 depicts the correlation (over rolling 60 day windows) between daily changes in Euro exchange rates and daily changes in our measure of risk neutral fair value which of course is dominated by daily changes in real interest rate differentials between Europe and US inflation indexed bonds. We see 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 Chart 1) as periods in which 'fundamentals' mostly matter for exchange rate determination, in contrast to periods since September 2008 in which 'fundamental' 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 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.

Chart 3



Pound

Chart 4

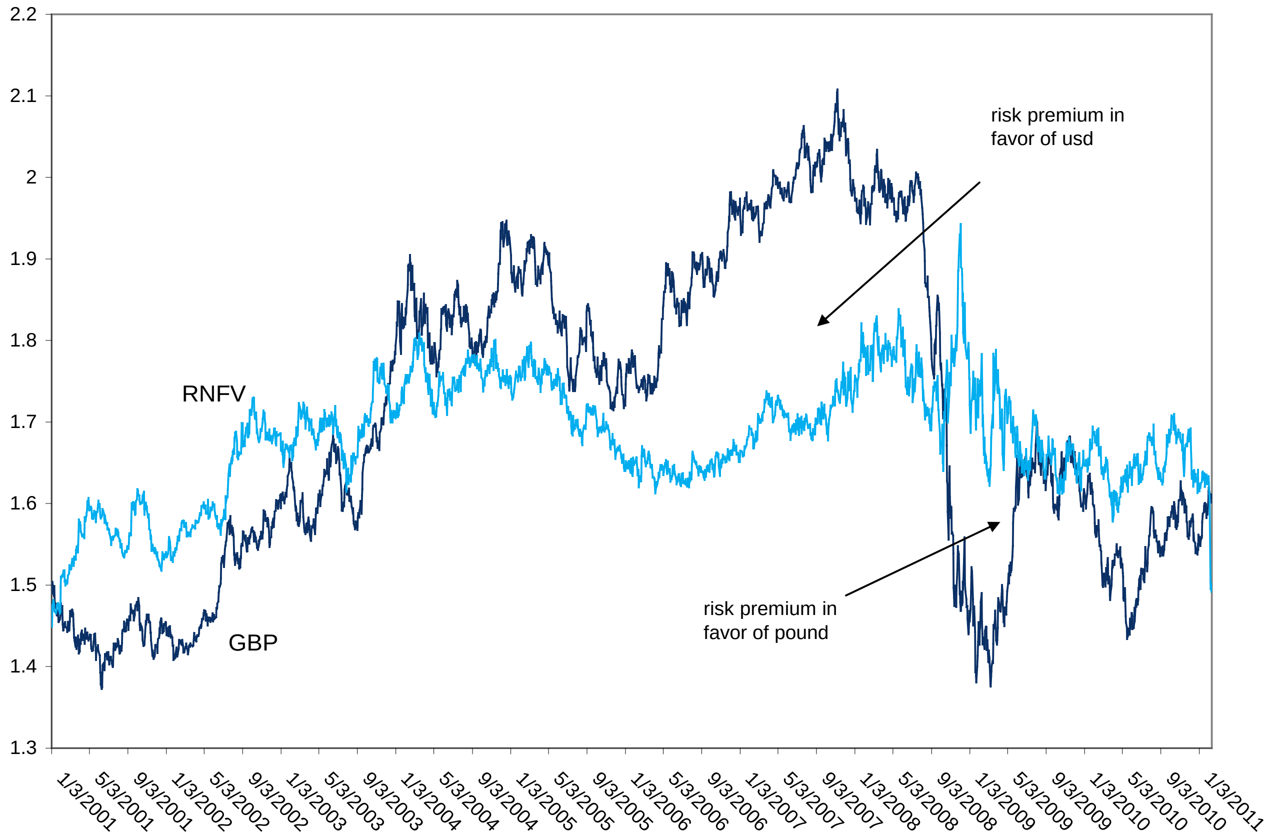


Chart 4 depicts our decomposition of the GBP exchange rate into is risk neutral fair value and risk premium components. From 2001 through summer of 2005, the appreciation of the pound from 1.50 to 1.75 is almost fully accounted for by an equal rise in our estimate of risk neutral fair value from the 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 a US 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.

Chart 5

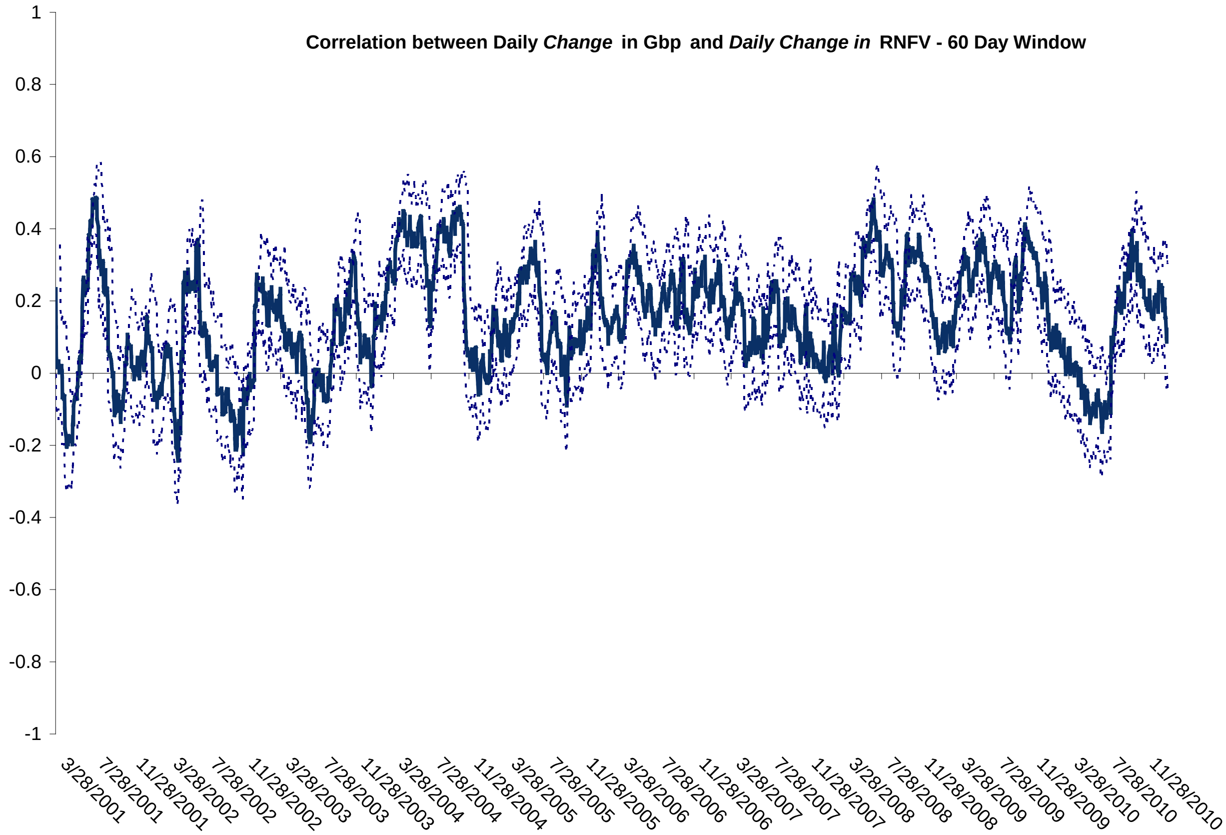


Chart 5 depicts the correlation (over rolling 60 day windows) between daily changes in GBP exchange rates and daily changes in our measure of risk neutral fair value Again we see that periods in which the correlation between daily changes is in the range of 0.3 to 0.5 are not uncommon. We also see that 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. The implies that large shocks to the risk premium in favor of the pound (or in Chart 1 the Euro) tend to require both depreciations of the exchange rate relative to the dollar – to set up the expectation of future appreciation - as well as a rise in the real interest rate differential in favor of the pound (or the Euro).

Yen

Chart 6

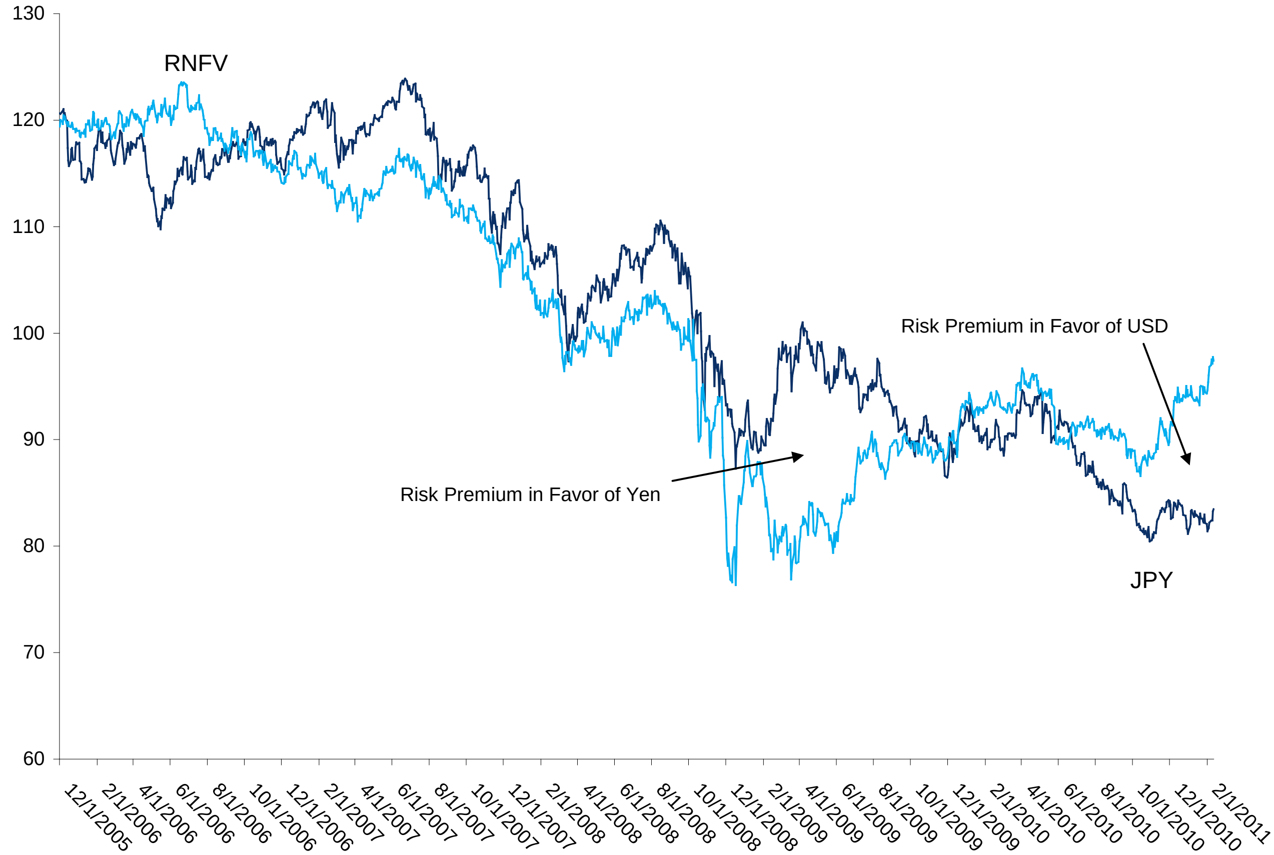
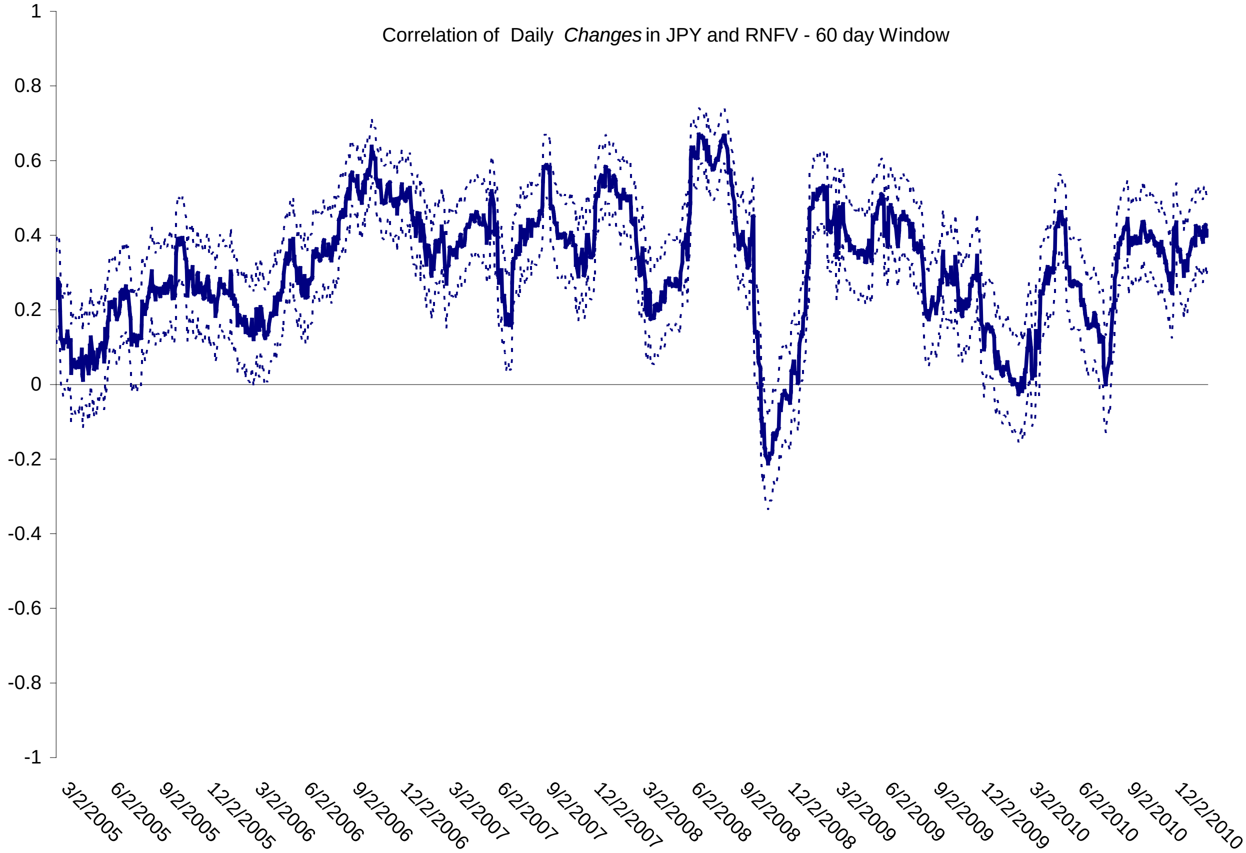


Chart 6 depicts our decomposition of the JPY exchange rate into is risk neutral fair value and risk premium components. From 2005 through summer of 2010, the appreciation of the yen from 120 to 88 is almost fully accounted for by an equal shift in our estimate of risk neutral fair value . During most 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 Chart 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.

Chart 7



Correlation of Daily *Changes* in JPY and RNFV - 60 day Window
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
3/2/2005
6/2/2005
9/2/2005
12/2/2005
3/2/2006
6/2/2006
9/2/2006
12/2/2006
3/2/2007
6/2/2007
9/2/2007
12/2/2007
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6/2/2008
9/2/2008
12/2/2008
3/2/2009
6/2/2009
9/2/2009
12/2/2009
3/2/2010
6/2/2010
9/2/2010
12/2/2010

VI. 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 rate as well as a 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 depending on the sub sample studied. However, sub samples 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 priorities 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.

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