

# Identifying Exchange Rate Common Factors\*

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March 27, 2016

## Abstract

Using recently developed model selection procedures, we determine that exchange rate returns are driven by a two-factor model and identify them as a dollar factor and a euro factor. Exchange rates are thus driven by global, US and Euro-zone stochastic discount factors. The identified factors can be given a risk-based interpretation. Identification motivates multilateral models for bilateral exchange rates. Out-of-sample forecast accuracy of empirically identified multilateral models dominate the random walk and a bilateral purchasing power parity fundamentals prediction model. 24-month ahead forecast accuracy of the multilateral model dominates those of a principal components forecasting model.

Keywords: Exchange rates, common factors, factor identification multilateral exchange rate model.

JEL Classification Number: F31, F37

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\*Some of the work was performed while Mark was a Visiting Fellow at the HKIMR (Hong Kong Institute for Monetary Research) and the Federal Reserve Bank of St. Louis. Research support provided by these institutions is gratefully acknowledged. This is a revision of a paper originally circulated in March 2012 under the title ‘Exchange Rates as Exchange Rate Common Factors.’ We have benefitted from comments by seminar participants at Michigan State University and the Bank of Canada. Thoughtful comments and suggestions from two anonymous referees helped us to improve the paper.

## Introduction

Exchange rate returns (first differences of log exchange rates) show substantial cross-sectional correlation. In a sample of 27 monthly exchange rate returns from 1999.01 to 2015.12, the average correlation is 0.43 when the U.S. dollar (USD) is the numeraire currency. Similarly, the average correlation is 0.32 when the euro is numeraire and 0.39 when the Canadian dollar is the numeraire.<sup>1</sup> Recent research has focused on understanding the source of these exchange rate co-movements. Engel et al. (2015) assume a factor structure for exchange rates and take a small number (2 or 3) of principal components to be the common factors. They find the principal components to remain significant after controlling for macroeconomic fundamental determinants and use them to predict future exchange rate returns. Verdelhan (2015) also assumes a two-factor structure and argues that a dollar exchange rate return and a carry exchange rate return are exchange rate common factors. He gives them a risk-based interpretation by showing the carry and dollar factors can account for two different cross-sections of currency risk premia.

In this paper, we obtain factor identification using econometric methods developed by Bai and Ng (2002, 2006) and Parker and Sul (2015). Our analysis identifies a two-factor structure consisting of a dollar factor and a euro factor. The analysis does not find the carry return to be a factor and identification is robust to the choice of the numeraire currency. The data support a risk-based interpretation to the factors. Using time-varying dollar and euro factor loadings to sort currency excess returns into portfolios, the average returns are increasing in their currency's loadings on the factors. The data also reveal a geographical dimension to the euro factor. European currencies generally load positively on the euro factor whereas all others generally load negatively. Commodity exporting countries tend to load positively on the dollar factor.

The methodology we use is designed to uncover the relationship between the vector of true but unobserved factors and a vector of economic variables put forth as candidates for empirical factors. The first step in the procedure uses an information criterion, proposed by Bai and Ng (2002), to determine the number  $k$ , of common factors in a panel of exchange rate returns. The second step determines the number of common factors in residuals from regressions of exchange rate returns on unique combinations of  $k$ -element groupings of the candidate economic variables. Identification is based on

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<sup>1</sup>This cross-sectional correlation has been recognized in research at least since O'Connell (1988) but has primarily been treated as a nuisance parameter in panel data models (Mark and Sul (2001), Engel et al. (2007))

the idea that if this particular group of  $k$  variables are empirical factors, then there are no common factors in the residuals. If one or more common factors are found in the residual panel, this particular set of variables is rejected as the empirical factors.

The candidate list of economic variables is potentially large. Searching over all possibilities is not feasible. We therefore limit empirical factor candidates to exchange rate returns. This is not unreasonable because exchange rate returns, being the difference between country's (possibly unobservable) log stochastic discount factors (SDF), may contain information that is difficult to observe in other macroeconomic fundamentals.

What is the value-added of empirical factor identification? One is that it guides us toward an economic interpretation of the source of exchange rate co-movements (as opposed to the descriptive principal components analysis). Drawing on the stochastic discount factor (SDF) approach to the exchange rate, as do Lustig et al. (2011) and Verdelhan (2015), implies that co-movements of exchange rate returns and log SDFs across countries are heavily influenced, if not dominated by the dynamics of the log SDF of the US and the Euro zone. We mount a limited exploration into a risk-based interpretation of the dollar and euro factors.

A second value to the identification is that it can be exploited to improve the performance of empirical exchange rate models. Our dollar and euro factor identification suggests a multilateral model of bilateral exchange rates which contrasts with typical bilateral formulations. That is, bilateral exchange rates in conventional models are determined by variables from the pair of countries associated with the bilateral exchange rate.<sup>2</sup> Instead fixating on details of every bilateral country pair, knowing the determinants of the dollar and the euro allows one to understand a substantial proportion of the variation in any bilateral exchange rate. To assess empirical model performance of the multilateral model, we employ an out-of-sample forecasting methodology which has been a standard procedure for model assessment since Meese and Rogoff (1983). We reserve the period from 2004.01 to 2015.12 for out-of-sample forecast evaluation and generate 1, 12, and 24 month ahead forecasts based on 60-month rolling regressions.

In the forecasting analysis, we compare our multilateral 'dollar-euro' model with alternative models considered in the literature. The first, is the bilateral purchasing-power parity (PPP) based fundamentals model (Bi-PPP). We use this as a comparison model because Engel et al. (2007) find that it gives the best forecast accuracy among

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<sup>2</sup>Berg and Mark (2015) is an exception. They argue that bilateral exchange rates are driven in part by third-country (rest of world) shocks.

several bilateral fundamentals-based formulations considered in the literature. We find that prediction accuracy from our dollar-euro model dominate those from the PPP-based model as well as those from the driftless random walk.

The empirical exchange rate literature finds that sample size matters for forecast accuracy. Rapach and Wohar (2001) and Lothian and Taylor (1996) report significant predictive power when working with long historical time-series data. To obtain more observations within the post Bretton Woods floating regime, a first-generation of papers (Mark and Sul, 2001, Rapach and Wohar, 2004, and Groen, 2005) expanded observations cross-sectionally with the use of panel-data methods. The panel aspect of our data expands observations by exploiting the cross section.

Improved forecast performance over the random walk and the bilateral PPP-based model does not fully answer the question of whether identification has predictive value in empirical modeling since the factor structure can also be estimated by principal components (PC) and used to forecast. Engel et al. (2015) found that quarterly forecasts from a two-principal components model were significantly more accurate than random walk predictions over the 1999 to 2007 period. When we compare the dollar-euro factor forecasts to the two-principal components model, we find, on balance, that the dollar-euro model has lower mean-square prediction error (MSPE) at the longer (24 month) horizons.

The paper is organized as follows. The next section presents the common factor structure that we assume and the identification methodology that we use. Our data set is described in Section 2. Empirical factor identification results are presented in Section 3. A limited exploration into geographical aspects of the factors and a possible risk-based interpretation of the factors is undertaken in Section 4. Forecasting results are presented in Section 5 and Section 6 concludes.

## 1 Common Factors in Exchange Rate Variation

This section develops the factor structure for exchange rate returns that guides our empirical work. To fix notation, let  $f_t$  be the  $k$ -dimensional vector of the true but unobserved common (global) factors and  $f_t^p$  be an  $m$ -dimensional vector of economic variables that are candidates for empirical identification as true common factors. Note that  $m$  is potentially very large. The goal is to identify a unique set of  $k$  elements from  $f_t^p$  that describe the evolution of  $f_t$ . We present ideas developed for the nominal

exchange rate. The parallel development for real exchange rates is straightforward, and omitted.

Let there be  $N + 1$  currencies. The USD (U.S. dollar) is currency ‘0.’ Nominal exchange rates  $s_{it}$  are stated as logarithms of the price of the USD in country  $i$  currency.  $s_{it}$  increases when the dollar appreciates. If within a country, markets are complete or if markets are incomplete but the law-of-one price holds and there is no arbitrage, the country will have a unique stochastic discount factor (SDF). SDFs differ across countries if there are cross-country risks that cannot be insured.<sup>3</sup> Let  $n_{it}$  be the log nominal stochastic discount factor for country  $i = 0, \dots, N$ . In the SDF approach to exchange rates, the exchange rate return is the difference between the log SDFs,

$$\Delta s_{it} = n_{it} - n_{0t}. \quad (1)$$

Because  $\Delta s_{it}$  varies (quite a bit) over time, we know that SDFs evolve differently across countries. A representation of the log SDF that is consistent with such cross-country heterogeneity is the factor structure,

$$n_{it} = \delta_i' f_t + n_{it}^o, \quad (2)$$

where  $\delta_i$  is a  $k$ -element vector of factor loadings and  $n_{it}^o$  is the idiosyncratic component of the country  $i$  log SDF. The latent factors may be correlated with each other  $\text{Cov}(f_{it}, f_{jt}) \neq 0$ , for  $i \neq j$ , while the idiosyncratic components are uncorrelated across countries,  $\text{Cov}(n_{it}^o, n_{jt}^o) = 0$ . Heterogeneous responses to factor movements across countries are necessary for exchange rate returns  $\Delta s_{it}$  to vary over time. If there were no cross-country differences in factor loadings  $\delta_i$ , the exchange return would be driven only by idiosyncratic components of the log SDF and would then be cross-sectionally uncorrelated. Because the factors  $f_t$  drive common movements in every country’s log SDF, they are global in nature. Lustig et al. (2011) and Verdelhan (2015) also decompose the log SDF into a common global component and a country-specific idiosyncratic component. We take eqs. (1) and (2) to represent the *truth*.

Substituting (2) into (1) gives the factor representation for exchange rate returns,

$$\Delta s_{it} = (\delta_i' - \delta_0') f_t + n_{it}^o - n_{0t}^o. \quad (3)$$

Notice from (3) that the idiosyncratic part of the numeraire country’s log SDF  $n_{0t}^o$ , appears for all  $i$  and is also a common source of exchange rate co-movement. Our interest

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<sup>3</sup>Markets are complete in Backus and Smith but home and foreign SDFs differ because risks associated with non-traded goods consumption shocks cannot be internationally traded.

is in the identification of  $f_t$ , not  $n_{0t}^o$ . To attenuate the numeraire effect of  $n_{0t}^o$  in exchange rate co-movements, we transform observations into deviations from the cross-sectional mean,

$$\frac{1}{N} \sum_{i=1}^N \Delta s_{it} = \Delta \bar{s}_t = (\bar{\delta}' - \delta_0') f_t - n_{0t}^o. \quad (4)$$

where  $\bar{\delta}' = \left( \frac{1}{N} \sum_{i=1}^N \delta_{i,1}, \dots, \frac{1}{N} \sum_{i=1}^N \delta_{i,k} \right)$  is the cross-sectional average of factor loadings and  $\tilde{\delta}'_i = (\delta'_i - \bar{\delta}')$  is the deviation from the mean loadings. In deviations from the cross-sectional mean form,  $\Delta \tilde{s}_{it} = \Delta s_{it} - \Delta \bar{s}_t$ , the  $n_{0t}^o$  component is removed and  $f_t$  is rendered the only common factor component of the exchange rate return,

$$\Delta \tilde{s}_{it} = \tilde{\delta}'_i f_t + \tilde{n}_{it}^o, \quad (5)$$

where  $\tilde{n}_{it}^o \rightarrow n_{it}^o$  as  $N \rightarrow \infty$ . Hence, the underlying factor structure in deviations from the mean form is numeraire invariant when  $N$  is large, but in any finite sample, changing the numeraire currency results in some variation in the  $\tilde{\delta}'_i$  factor loadings.<sup>4</sup>

## 1.1 Identification Method

The common factor representation has successfully been used as the statistical foundation for modeling co-movements across exchange rates but because the factors are not identified, the economic interpretation for the underlying mechanism is not obvious. To address this issue, Bai and Ng (2006) and Parker and Sul (2015) develop econometric methods to identify the unobserved common factors with observed economic variables. In this section, we draw on these methods to identify the common factors for exchange rate returns. The procedure involves two steps. The first step identifies the number of common global factors  $k$  present in the data. The second step evaluates restrictions imposed on candidate empirical factors by the factor representation to identify those economic variables that closely mimic the  $k$  true latent factors.

The panel data are  $N$  exchange rate returns over  $T$  time periods in deviations from the mean form  $\Delta \tilde{s}_{it}$ . The number  $k$  of common factors is identified using Bai and Ng's (2002)  $IC_2$  information criterion on standardized observations.<sup>5</sup> Let  $C_{NT} = \min(N, T)$ ,

<sup>4</sup>If the US is the numeraire country,  $\bar{\delta}$  is the average of all other (not US) country factor loadings. If instead, Canada is used as the numeraire, Canada's factor loadings are replaced by the US's  $\delta$  in computing the average,  $\bar{\delta}$ . The effect of swapping numeraires on  $\tilde{\delta}_i$  vanishes when  $N$  is large.

<sup>5</sup>Bai and Ng (2002), Hallini and Liska (2007), Onatski (2009, 2010), Ahn and Horenstein (2013) propose alternative

and  $\lambda_i$  be the  $i$ th largest eigen value of the sample covariance matrix. The information criterion is

$$\text{IC}_2 = \ln \left( \sum_{i=k+1}^{C_{NT}} \lambda_i \right) + k \left( \frac{N+T}{NT} \right) \ln C_{NT}. \quad (6)$$

and the number of common factors in the panel is the value of  $k$  that minimizes (6).

For concreteness and to foreshadow our findings, assume step 1 determines exchange rates  $\Delta \tilde{s}_{it}$  are driven by  $k = 2$  common factors. In step two, viewing eq.(5) as the true factor representation, we test the null hypothesis that a unique pair of economic variables  $(f_{jt}^p, f_{st}^p)$  span the same space as the two true common factors  $(f_{1t}, f_{2t})$ ,

$$f_{1t} = a_{11}f_{jt}^p + a_{12}f_{st}^p + \epsilon_{1t}, \quad (7)$$

$$f_{2t} = a_{21}f_{jt}^p + a_{22}f_{st}^p + \epsilon_{2t}, \quad (8)$$

where for  $j = 1, 2$ ,  $\text{Var}(\epsilon_{jt}) \rightarrow 0$  as  $T \rightarrow \infty$ . Asymptotically, the economic variables give an exact identification of the factors in the sense that the error terms are  $O_p\left(1/\sqrt{T}\right)$ . It is also possible that some of the  $a_{js}$  coefficients are zero. If, for example,  $a_{12} = a_{21} = 0$ , the latent factors are uniquely identified. This implies that the residuals  $\Delta s_{it}^o$ , from regressions of  $\Delta \tilde{s}_{it}$  on  $(f_{jt}^p, f_{st}^p)$ ,

$$\Delta \tilde{s}_{it} = a_i + b_{1i}f_{jt}^p + b_{2i}f_{st}^p + \Delta s_{it}^o \quad (9)$$

have no common factors. We are guided by the following two results, established by Parker and Sul (2015).

1. If there are no (zero) common factors in the panel of residuals  $\Delta s_{it}^o$ , then  $(f_{jt}^p, f_{st}^p)$  are the true common factors.
2. If there are one or more common factors in the panel of residuals  $\Delta s_{it}^o$ , then either  $(f_{jt}^p$  or  $f_{st}^p)$ , or both  $(f_{jt}^p, f_{st}^p)$  are not the true common factors.

Hence we examine whether pairs of economic variables are approximately the true factors by regressing  $\Delta \tilde{s}_{it}$  on all combinations of two candidates  $f_{st}^p$  and  $f_{jt}^p$  then using the  $\text{IC}_2$  information criteria (6) to determine the number of common factors in the regression residuals. If there are no common factors in the panel of residuals, then  $f_{st}^p$  and  $f_{jt}^p$  are identified as empirical factors.

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methods to determine the number of common factors. We employ Bai and Ng's (2002)  $\text{IC}_2$  because Parker and Sul (2015) showed that it has good robustness properties.

## 2 Data

Observations are split into two data sets. The first, which we refer to as the euro epoch data, consists of exchange rates and interest rates of  $N = 27$  countries from 1999.01 to 2015.12. Currency selection was based on data availability and whether or not countries allowed their exchange rate to float. Factor identification is more precise when  $N$  is large and when exchange rates are flexible. Little or no information is contributed by adding exchange rates that are pegged. Currencies included in the sample were consistently classified as either “floating” or “managed floating without a predetermined path” in the IMF *Annual Report on Exchange Arrangements and Exchange Restrictions*.<sup>6</sup>

The euro epoch data emphasizes the important role played by the euro in international finance and reflects a trend among emerging market economies to allow their exchange rates to float. The euro epoch data consists of the currencies of Australia (AUS), Brazil (BRA), Canada (CAN), Chile (CHI), Columbia (COL), the Czech Republic (CZE), the Euro (EUR), Hungary (HUN), Iceland (ICE), India (IND), Israel (ISR), Japan (JPN), Korea (KOR), Mexico (MEX), Norway (NOR), New Zealand (NZL), the Philippines (PHI), Poland (POL), Romania (ROM), Singapore (SIN), South Africa (RSA), Sweden (SWE), Switzerland (SUI), Taiwan (TWN), Thailand (THA), Turkey (TUR), the U.K. (GBR) and the U.S. (USA).<sup>7</sup>

As seen in Table 1, the euro has consistently been the second most important currency (behind the U.S. dollar) in terms of foreign exchange market turnover. An attractive feature of the euro epoch data is it does not extend across different regimes or institutional structures.

The second data set is from the pre-euro epoch and is of more historical interest, spanning time from 1983.10 to 1998.12. The pre-euro currencies are from AUS, CAN, GBR, GER, ICE, ISR, JPN, KOR, NOR, NZL, PHI, RSA, SIN, SWE, SWI, and USA. Many of the European currencies are excluded because they were effectively pegged to the deutschemark during the European Monetary System. Similarly, we exclude emerging market currencies as they were generally pegged to the USD during that time.

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<sup>6</sup>The IMF report does not cover Taiwan since it is not part of the IMF. We include it in the sample however since the central bank of Taiwan states it uses a managed floating regime. In any case, the standard deviation of monthly returns of the USD/New Taiwan dollar is 1.48% between 1999.01 and 2015.12, which is of similar order of magnitude as that of the Singapore dollar 1.81%, which has consistently been classified as a “managed float with no pre-determined path” by the IMF.

<sup>7</sup>Country abbreviations follow International Olympic Committee three-letter country codes (except Taiwan, which we designate as TWN).

Exchange rates are end-of-month point-sampled and obtained from IHS Global insight. We also use implied interest rate differentials through the forward premium to construct the carry factor exchange rate return.<sup>8</sup>

### 3 Empirical Factor Identification

A large number of macro and financial variables potentially have influence on bilateral exchange rates. What economic variables should we include in the vector  $f_t^p$ ? To narrow down the set of candidates, our search for common factors is restricted to exchange rate returns. One of the returns we consider is the ‘carry,’ studied by Verdelhan (2015). In his examination of nominal exchange rate returns with the USD as the numeraire currency, he concludes that exchange rates have a two-factor representation consisting of a dollar factor, which is the average of the cross-section of exchange rate returns  $\Delta \bar{s}_t$ , and a ‘carry factor,’ which is the cross-rate currency return on a portfolio of high interest rate countries relative to a portfolio of low interest rate countries. He calls this exchange rate return the carry, because a (portfolio) carry trade is formed by taking a short position in the low interest rate portfolio and using the proceeds to take a long position in the high interest rate portfolio. Verdelhan (2015) gives a risk-based interpretation to the factors. The dollar risk is interpreted as a global macro-level risk and the carry as representing volatility and uncertainty risk. On account of his findings, we also consider the carry as a factor candidate.

The carry return is constructed as follows. For each time period  $t$ , sort the countries by their interest rate and divide, alternatively, into quintiles, quartiles, and tertiles from low to high. Let  $N_{Ht}$  be the number of countries in the highest quantile and  $N_{Lt}$  be the number in the lowest quantile.<sup>9</sup> The nominal carry exchange rate return  $\Delta \bar{s}_t^c$  is the cross exchange rate return between  $P_{Ht}$  and  $P_{Lt}$  currencies,

$$\Delta \bar{s}_t^c \equiv \frac{1}{N_{Ht}} \sum_{j \in P_{Ht}} \Delta s_{jt} - \frac{1}{N_{Lt}} \sum_{i \in P_{Lt}} \Delta s_{it}. \quad (10)$$

The carry return constructed this way rebalances the portfolios each period depending on the rank ordering of interest rates. We refer to this as the conditional carry return. We also consider an unconditional carry return, where the portfolios are sorted once

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<sup>8</sup>By covered interest parity, the forward premium is equal to the interest differential. We follow the literature (e.g., Verdelhan (2015)) which routinely uses the forward premium to measure the interest differential.

<sup>9</sup>The carry trade takes a USD short position in the  $P_L$  portfolio and use the proceeds to take a corresponding USD long position in the  $P_H$  portfolio. This return is accessible to investors in any country.

and for all in 1998.12 based on the average interest rates for developed countries from 1990.01 to 1998.12<sup>10</sup> Additional details on the construction of the carry factor can be found in the Appendix.

The other variables in our candidate list  $f_t^p$ , are the cross-sectional averages of alternative numeraire exchange rates. These are alternative country  $i$  versions of the dollar factor. If  $s_{it}^e = s_{it} - s_{euro,t}$  is the log currency  $i$  price of the euro, the euro factor candidate,  $\Delta \bar{s}_t^e = N^{-1} \sum_{i=1}^N \Delta s_{it}^e$ , is the cross sectional average of individual bilateral exchange rate returns with the euro as numeraire. In the euro-epoch data set, there are 27 such factor candidates.

*Empirical identification in the euro-epoch sample.* The  $IC_2$  employed on the euro-epoch sample of standardized and unstandardized exchange rate returns in deviation from mean form,  $\{\Delta \tilde{s}_{it}\}$ . Taking the minimum of the two determines there to be  $k = 2$  common factors. Using other methods, Verdelhan (2015) and Engel et al (2015) also determine that there are 2 common factors in exchange rates.

Given that there are 2 factors, we run the Parker-Sul identification on all possible pairs of factor candidates. There are 27 numeraire factor candidates plus 3 carry candidates, which vary by portfolio sizes (sorted into quintiles, quartiles or tertiles). To test if the dollar and the euro are factors, take residuals from the regression  $\Delta \tilde{s}_{it} = \alpha_i + \tilde{\delta}_{1i} \Delta \bar{s}_t + \tilde{\delta}_{2i} \Delta \bar{s}_t^e + \Delta s_{it}^o$  and use  $IC_2$  to determine the number of common factors in the panel  $\{\Delta s_{it}^o\}$ . Do this for all pairs of candidates. To check robustness over time, we also run the procedure on 47 recursively backdated samples. The sample always ends on 2015.12. The first sample runs from 2002.11 to 2015.12, the second from 2002.10 to 2015.12, and so on through the last sample which runs from 1999.02 to 2015.12. We always find the dollar  $\Delta \bar{s}_t$ , to be a factor.

Table 2 reports the proportion of samples that finds a variable to be a common factor along with the dollar factor. As there are a great number of results, the table reports only a subset of the essentials. Look at the first row labeled USA. These are results using the USD as numeraire. Conditional on the dollar factor, the table reports the proportion of samples the candidate is detected as a factor. ‘EUR’, ‘JPN’, and ‘SWI’ stand for the cross sectional averages of the depreciation rates with the numeraires of Euro, yen and Swiss franc. The entry 1 under the EUR column indicates that a dollar and a euro factor

<sup>10</sup>The set of developed countries is AUS, CAN, GBR, GER, ICE, ISR, JPN, KOR, NOR, NZL, SIN, SWE, SWI, TWN, USA.

has been found in all 47 samples. The 0 entry under the JPN column says conditional on the dollar, the yen is never determined to be a factor. Similarly, the Swiss franc is never found to be a factor. Moving further across the row, we form the carry return sorting over all countries in the sample alternatively into quintiles, quartiles and tertiles (see eq. (10)). Carry factors constructed by deleting the currency being analyzed from the carry portfolios and are standardized. (Results with non-deletion are exactly the same.) Conditional on the dollar, none of the carry candidates are determined to be factors in any sample.

Since the observations are deviations from the cross-sectional mean, identification is asymptotically (as  $N \rightarrow \infty$ ) robust to numeraire choice. In any finite sample, this may not be true. The other rows in the table run the identification procedure using alternative currencies as the numeraire.

The overwhelming evidence finds a dollar and a euro factor. Having found the dollar and the euro to be factors, when either the dollar or the euro is the numeraire, it doesn't matter if exchange rate returns are expressed as deviations from the mean or not. Say the dollar is numeraire. The factor structure for deviations from the mean is  $\Delta \tilde{s}_{it} = \tilde{\delta}_{i1} \Delta \bar{s}_t + \tilde{\delta}_{i2} \Delta \bar{s}_t^e + \epsilon_{it}$ . If we don't take deviations from the mean, it is still the two-factor structure,  $\Delta s_{it} = (\tilde{\delta}_{i1} + 1) \Delta \bar{s}_t + \tilde{\delta}_{i2} \Delta \bar{s}_t^e + \epsilon_{it}$ . This is true also when the euro is the numeraire. Now suppose currency  $j$  is the numeraire. The exchange rate panel consists of  $\Delta \tilde{s}_{it}^j = \Delta s_{it}^j - \Delta \bar{s}_{it}^j$  where  $s_{it}^j = s_{it} - s_{jt}$  is the price of currency  $j$  in terms of currency  $i$ . The structure is a dollar and euro factor structure for deviations from the mean,  $\Delta \tilde{s}_{it}^j = \delta_{i1} \Delta \bar{s}_t + \delta_{i2} \Delta \bar{s}_t^e + \epsilon_{it}$ , but for the not demeaned return,  $\Delta s_{it}^j = \delta_{i1} \Delta \bar{s}_t + \delta_{i2} \Delta \bar{s}_t^e + \Delta \tilde{s}_{it}^j + \epsilon_{it}$ . That is,  $\Delta \bar{s}_{it}^j$  is also a common factor.

When the euro is the numeraire, there is some light evidence that the dollar and Swiss franc are factors. Probably, this is because the Swiss franc was pegged to the euro from Sept 2011 through Jan 2015. The Czech koruna is not technically pegged to the euro but the Czech National Bank set a floor for the koruna (against the euro) since November 2013. No evidence is found for the yen to be a factor, nor for any of the candidate carry factors.

*Empirical identification in the pre-euro-epoch sample.* The last observation in the pre-euro sample is 1998.12. The first sample runs from 1987.11 and the last sample begins in 1983.11 so that identification is also performed on 47 recursively back-dated samples. The cross-section is smaller because currencies of emerging market economies in the

euro-epoch sample either were not convertible or were pegged. We do not attempt to combine the euro and pre-euro epoch samples because the disappearance and emergence of currencies over time introduces blocks of zeros in the cross-moment matrix from which eigenvalues are computed for the IC<sub>2</sub>, which makes the procedure unreliable.<sup>11</sup>

Results for the pre-euro epoch sample are displayed in Table 3. Our findings are similar to those from the euro-epoch sample. The cross-section of dollar and deutchemark exchange rate returns are found to be factors in the vast majority of the samples. In instances where the deutchemark is not found to be a factor (e.g., Norwegian krone as numeraire), no other currency nor any of the carry variables are found to be factors.

*Empirical identification with Verdelhan’s method.* Verdelhan identifies the dollar and carry returns to be factors by obtaining significant t-ratios on  $\beta_2, \beta_3, \beta_4$  in regressions of country  $i$ ’s currency depreciation on the dollar factor, the carry factor, and the  $t + 1$  carry return interacted with the time  $t$  interest differential,

$$\Delta s_{it+1} = a + \beta_1 (r_{it} - r_{0t}) + \beta_2 \Delta \bar{s}_{t+1} + \beta_3 \Delta s_{t+1}^c + \beta_4 \Delta s_{t+1}^c (r_{it} - r_{0t}) + \epsilon_{1t+1} \quad (11)$$

Here,  $r_{it}$  is interest rate of country  $i$ ,  $r_{0t}$  is nominal interest rate of US. The regression controls for the effect of the interest differential through uncovered interest parity. He calls the interaction term the ‘conditional carry’ factor, which tries to capture the idea that the co-movement between the carry factor and country  $i$  exchange rate return is higher in times when the interest differential is bigger.

We estimate (11) with our data. Whether a currency is pegged or floats does not introduce complications to this regression methodology here so we combine the euro and pre-euro samples. We also include, in the pre-euro sample the currencies of Belgium (BEL), France (FRA), Italy (ITA) and the Netherlands (NET). For each currency, we use as many observations as available, beginning 1983.10. Observations for European currencies in the euro-zone end in 1999.01, while observations for the euro begin in 1999.01. The carry factor is generated by sorting countries into quintiles on the basis of their interest rates. The t-ratios on the dollar factor coefficient is always highly significant and is not reported. T-ratios for the key coefficients ( $\beta_3$  and  $\beta_4$ ) are shown on the left side of Table 4. Our estimates of eq(11), as in Verdelhan (2015) shows the regression has high explanatory power. The  $\bar{R}^2$  values range from 0.23 (PHI) to 0.93

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<sup>11</sup>If  $X$  is the panel of residuals, the number of factors identification requires calculation of  $\text{Trace}(XX')$ . We do not combine pre and post euro epoch countries because the available currencies would be added and disappear at points in time. The presence of blocks of zeros in  $XX'$  creates a problem for the identification procedure.

(BEL). The carry is significant at the 5% level for 19 of 33 exchange rates. The carry interacted with the interest differential is significant for 8 exchange rates.

Now, what happens if we add the euro factor as a regressor to eq.(11)? The right side of Table 4 shows t-ratios for  $\beta_3, \beta_4$  and  $\beta_5$  from estimating

$$\Delta s_{it+1} = a + \beta_1 (r_{it} - r_{0t}) + \beta_2 \Delta \bar{s}_{t+1} + \beta_3 \Delta s_{t+1}^c + \beta_4 \Delta \bar{s}_{t+1}^c (r_{it} - r_{0t}) + \beta_5 \Delta \bar{s}_{t+1}^e + \epsilon_{1t+1} \quad (12)$$

Here, we see the euro factor is significant for 26 exchange rates. The interaction terms continue to be significant for 8 exchange rates but the carry is now significant for only 10 exchange rates. The adjusted  $R^2$  values all increase except for ISR.

Table 5 reports the t-ratios on the coefficients of interest estimated on the euro-epoch sample. These results tell a similar story. Whereas the carry is significant for 16 exchange rates in estimating (11), it is significant only for 8 exchange rates when the equation is augmented by the euro factor. The euro factor is significant in 22 of 27 exchange rates. Adding the euro factor increases the  $\bar{R}^2$  in every instance.

To summarize this section, our evidence shows exchange rate returns are driven by a two-factor structure. We identified a dollar factor and a euro factor. The carry return is not identified to be an exchange rate common factor using the Parker-Sul method. Verdelhan's regression method is less definitive. It provides strong evidence that the euro currency return is an exchange rate common factor is strong and only weak evidence that the carry factor is an exchange rate common factor. The similarity in the adjusted  $R^2$  values in Tables 4 and 5 says the euro factor and carry factors share common information but the lower significance of the carry in the Parker-Sul and in the Verdelhan methodologies leads to the conclusion that exchange rate dynamics are more directly linked and driven by the euro factor.

## 4 Characteristics of the Identified Factors

Researchers frequently assume the principal components are the factors. Figure 1 plots the cumulated dollar factor and the cumulated first principal component. Figure 2 compares the cumulated euro factor with the cumulated second principal component. While there are similarities between our identified factors and the principal components, but they are not the same. Principal components are constructed under the identifying assumption that they are orthogonal to each other. The factor representation allows the factors to be correlated with each other. The correlation between  $\Delta \bar{s}_t$  and the first

principal component is 0.996, between  $\Delta\bar{s}_t^e$  and the second principal component is 0.8 and the correlation between the dollar and the euro factors is  $-0.267$ . Generalized strength in the dollar are associated with generalized weakening of the euro.

To give some context for our identification, the implied relationship between the latent factors and the dollar and euro empirical factors is

$$f_{1t} = a_{11}\Delta\bar{s}_t + a_{12}\Delta\bar{s}_t^e + \epsilon_{1t}, \quad (13)$$

$$f_{2t} = a_{21}\Delta\bar{s}_t + a_{22}\Delta\bar{s}_t^e + \epsilon_{2t}. \quad (14)$$

As before, let USA be country 0 and let the euro-zone be country 1. Note that  $\Delta\bar{s}_t^e = \Delta\bar{s}_t - \Delta s_{1,t}$ . Recall from (2), country  $i$ 's log SDF has a two-factor structure, which when employed in eqs.(13), (14) gives<sup>12</sup>

$$\begin{aligned} f_{1t} &= a_{11}\Delta\bar{s}_t + a_{12}(\Delta\bar{s}_t - \Delta s_{1,t}) + \epsilon_{1t} \\ &= (a_{11} + a_{12}) \underbrace{[\bar{n}_t - n_{0t}]_{\Delta\bar{s}_t}} - a_{12} \underbrace{[\bar{n}_t - n_{1t}]_{\Delta s_{1t}}} + \epsilon_{1t} + O_p(N^{-1}) \\ f_{2t} &= a_{21}\Delta\bar{s}_t + a_{22}(\Delta\bar{s}_t - \Delta s_{1,t}) + \epsilon_{2t} \\ &= (a_{21} + a_{22}) \underbrace{[\bar{n}_t - n_{0t}]_{\Delta\bar{s}_t}} - a_{22} \underbrace{[\bar{n}_t - n_{1t}]_{\Delta s_{1t}}} + \epsilon_{2t} + O_p(N^{-1}) \end{aligned}$$

Recalling the linear factor representation for the nominal SDF  $n_{it} = \delta_{1i}f_{1t} + \delta_{2i}f_{2t} + n_{it}^0$  after some algebra yields

$$n_{it} = b_{1i}\bar{n}_t - b_{2i}n_{0t} - b_{3i}n_{1t} + \delta_{1i}\epsilon_{1t} + \delta_{2i}\epsilon_{2t} + n_{it}^0 \quad (15)$$

where

$$\begin{aligned} b_{1i} &= \delta_{1i}(a_{11} + a_{12}) + \delta_{2i}(a_{21} + a_{22}), \\ b_{2i} &= \delta_{1i}a_{11} + \delta_{2i}a_{21}, \\ b_{3i} &= \delta_{1i}a_{12} + \delta_{2i}a_{22}. \end{aligned}$$

Every country's log SDF is seen to be connected to the global log SDF  $\bar{n}_t$ , the US log SDF  $n_{0t}$  and the Euro-zone log SDF  $n_{1t}$ . Upon substitution of (15) into (1), exchange rate returns are seen to be governed by the US, euro and a global ( $\bar{n}_t$ ) log SDF. That is,

$$\Delta s_{it} \rightarrow b_{1i}\bar{n}_t - b_{2i}n_{0t} - b_{3i}n_{1t} \text{ as } N, T \rightarrow \infty.$$

<sup>12</sup>Note that  $\bar{n}_t = \frac{1}{N} \sum_{i=1}^N n_{it}$  and  $\Delta\bar{s}_t^e = \frac{1}{N} \sum_{i \notin 1}^N n_{it} - n_{1t} = \bar{n}_t^1 - n_{1t}$ . But the difference between  $\bar{n}_t$  and  $\bar{n}_t^1$  goes to zero as  $N \rightarrow \infty$ . This is because  $\bar{n}_t - \bar{n}_t^1 = \frac{1}{N} (n_{1t} + \dots + n_{Nt}) - \frac{1}{N} (n_{0t} + n_{2t} + \dots + n_{Nt}) = \frac{1}{N} (n_{1t} + n_{0t}) = O_p(N^{-1})$  since both  $n_{1t}$  and  $n_{0t}$  are  $O_p(1)$ .

*Geographical patterns.* Table 6 shows estimates of the identified factor structure. These are regressions of eq.(9) with the dollar factor for  $f_{1t}^p = \Delta\bar{s}_t$  and the euro factor for  $f_{2t}^p = \Delta\bar{s}_t^e$ . We estimate by regressing the deviations from the mean  $\Delta\tilde{s}_{it}$  so the results are numeraire invariant. Results are broken down by geographical classification. Estimation is for the euro-epoch data set.

In regressions of  $\Delta\tilde{s}_{it}$ , explanatory power of the identified two-factor model is high with  $R^2$  ranging from 0.02 (ICE) to 0.62 (TWN). The dollar factor loadings are generally positive for European and commonwealth countries (not Canada), which says conditional on the euro, a rise in the USD is associated with a decline in these currencies. Conditional on the euro, dollar gains tend to be associated with gains in Asian currencies which load negatively on the dollar factor. Except for Mexico and Canada, who share a border with the US, load negatively on the dollar factor (their currencies rise with the dollar), those that load positively on the dollar tend to be commodity currencies.

The euro factor loads negatively on European exchange rates and positively on all others (except JPN). The negative loadings says when the euro gains, European currencies also gain. Non European currencies fall relative to the dollar when the euro gains. There is a distinct geographical pattern in the factor loadings. There is also a shred of evidence that countries that share risk better with the euro-zone load negatively on the euro factor. Regressing the euro-factor loadings on the  $R^2$  from regressing a country's consumption growth rate on euro-zone consumption growth gives a slope of  $-1.064$  (t-ratio  $-1.816$ ) and  $R^2 = 0.121$ . A positive loading says when the euro gains, that currency loses and is associated with lower consumption correlation with the euro-zone.<sup>13</sup>

*A Risk-Based Interpretation.* The tight connection between exchange rates and stochastic discount factors and the role of SDFs in pricing assets suggests there may be a risk-based interpretation to the factor structure. We pursue this interpretation along the lines developed in Verdelhan (2015).

The operation goes as follows. At date  $t$ , estimate the factor structure on a width  $k$  backward looking window of observations

$$\Delta\tilde{s}_{it} = a_i + \delta_{1i}\Delta\bar{s}_t + \delta_{2i}\Delta\bar{s}_t^e + \epsilon_{it}, \text{ for } t = t_0 - k + 1, \dots, t_0, \quad (16)$$

where  $\Delta\bar{s}_t$  is the dollar factor and  $\Delta\bar{s}_t^e$  is the euro factor. Currency  $i$  is omitted in construction of both factors. Next, sort the time-varying factor loadings  $\hat{\delta}_{1i,t_0}$  and  $\hat{\delta}_{2i,t_0}$

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<sup>13</sup>Annual consumption data are from Penn World Tables version 8.1 (Feenstra, Inklaar and Timmer (2015)).

from smallest to the largest and form three portfolios of currency excess returns grouped by the ranking on dollar exposure  $(\hat{\delta}_{1i,t_0})$  and three portfolios grouped by ranking on euro exposure  $(\hat{\delta}_{2i,t_0})$ . The investor takes a long position in all the dollar portfolios if the average interest differential  $(\frac{1}{N} \sum_i r_{i,t}) - r_{0,t}$  at time  $t_0$  is positive, and short if the differential is negative. Similarly, the investor takes a long position in all the euro-beta sorted portfolios if the average interest differential with respect to the euro-area  $(\frac{1}{N} \sum_i r_{i,t}) - r_{e,t}$  is positive.<sup>14</sup> Note that each currency appears in both a dollar ‘beta-sorted’ portfolio and a euro ‘beta-sorted’ portfolio.

To fix ideas, consider the euro beta-sorted portfolios. Denote the return differential on the euro-beta sorted portfolio  $P_j$ ,  $j = 1, \dots, 3$  by

$$\bar{r}_{j,t_0+1}^e = \frac{1}{N_{P_j,t}} \sum_{i \in P_j,t} (r_{i,t} + \Delta s_{i,t+1}^e) - r_{e,t}$$

where  $N_{P_j,t}$  is the number of currencies in portfolio  $j$  at time  $t$ , and  $s_{i,t}^e$  is the log currency  $i$  price of the euro. We refer to these as simple euro excess returns, to distinguish them from the risk-factor, which we discuss next. The simple excess returns will serve as returns on our ‘test assets.’

The aggregate portfolio excess return is interpreted as the risk factor, and is

$$RE_{t_0+1}^e = \sum_{j=1}^3 \bar{r}_{j,t_0+1}^e \cdot I \left( \frac{1}{N} \sum_i r_{i,t} - r_{e,t} \right)$$

where  $I(\cdot) = 1$  if the argument is positive and is  $-1$  if the argument is negative. We refer to  $RE_t^e$  as the conditional euro beta-sorted excess return, because its realization is conditional on interest rates. We construct the conditional return for each  $t_0 = k, \dots, T-1$ , and estimate a two-factor beta-risk model with the constructed returns. An analogous construction is made for dollar beta-sorted portfolios. Call the analogous returns  $\bar{r}_{j,t_0+1}^U$  and  $RE_{j,t_0+1}^U$ . Stack the test-asset returns in the vector  $y_t = (\bar{r}_{1,t}^U, \dots, \bar{r}_{3,t}^U, \bar{r}_{1,t}^e, \dots, \bar{r}_{3,t}^e)'$ , and the risk-factors in the vector  $x_t = (RE_t^U, RE_t^e)'$ . Using the Fama-MacBeth method, the first stage is the time-series regression of the return differential on the portfolio excess return.

$$y_{it} = a_i + x_t' \beta_i + \epsilon_{it} \tag{17}$$

for  $t = t_0, t_0+1, \dots, T$ ,  $i = 1, \dots, 6$ , and  $\beta_i = (\beta_{i,u}, \beta_{i,e})'$  are the betas on the dollar and euro risk factors. As in Verdelhan (2015), we then run the cross sectional regression of the average returns on the test assets without a constant,

<sup>14</sup>We are applying the Lustig et al. (2014) investment strategy for the dollar to the dollar and the euro.

$$\bar{y}_i = \lambda' \hat{\beta}_i + \alpha_i \quad (18)$$

where  $\bar{y}_i$  is the time-series average of  $y_{i,t}$  and  $\alpha_i$  is the ‘pricing error.’

Table 7 reports the results. The beta-risk model is estimated on observations from 1999.01 to 2015.12. The initial rolling factor loadings ( $\delta_{i1}, \delta_{i2}$ ) are estimated on observations from 1994.01 through 1999.01. The model is estimated by the Fama-MacBeth two-stage method with GMM standard errors on the risk-premium estimates to account for the generated regressors problem in the second stage. We use the deutchemark in place of the euro for 1994.01 through to 1998.12 in the rolling regressions.

Returns are stated in percent per annum. Primary support for a risk-based interpretation of the factors is provided by the mean simple excess currency returns. The mean returns on these portfolios are increasing in the currency’s exposure to the dollar and euro factors. The portfolios sorted by euro-factor loadings is new. Interestingly, the simple excess returns are driven more heavily by interest differentials than by exchange rate depreciation.

The dollar risk premium estimate  $\lambda_U$  is 2.9 percent (p-value = 0.11) whereas the euro risk premium estimate is 3.9 percent (p-value = 0.031). The test for randomness in the pricing errors is insignificant and the second stage  $R^2$  is a respectable 0.83.<sup>15</sup> Figure 3 plots the actual and predicted excess returns.

To summarize, the empirical factor identification is useful in that it helps to give an economic interpretation for cross-currency co-movements of exchange rates. The data reveal both geographical and risk-based dimensions to the dollar and euro factors. In the next section, we show that the identification can also work to improve empirical exchange rate models in terms of their ability to forecast.

## 5 Multilateral Empirical Exchange Rate Modeling

This section conducts an out-of-sample forecasting exercise with the factor models. Although Inoue and Kilian (2004) point out that In-sample tests are more powerful than out-of-sample tests in testing the predictability of exchange rates, ever since Meese and Rogoff (1983), it has been customary practice to evaluate empirical exchange rate models by their out-of-sample forecast accuracy. Our dollar-euro factor identification motivates

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<sup>15</sup>  $R^2$  statistics are calculated using the sum of squared dependent variables (not de-means) in the denominator to ensure that they are positive.

a particular *multilateral* forecasting model for bilateral exchange rates. We generate forecasts for nominal exchange rate returns at 1, 12, and 24 month horizons. The USD is the numeraire. Forecast ability for any pair of exchange rates implies forecast ability for the associated cross rate.<sup>16</sup>

Exchange rates are an asset price. As in other asset-pricing research, exchange rate forecasting aims to exploit information contained in the deviation of the exchange rate from a fundamental value which is thought to be a measure of central tendency. The strategy shares much with studies of stock prices where variables such as the dividend-price ratio or book value relative to market value of firms predict future equity returns. For stock prices, a certain multiple of dividends (or book value) plays the role of the central tendency for price.

The identification of the dollar and euro factors lead us to forecast  $h$ -period ahead exchange rate returns with the empirical model,

$$s_{it+h} - s_{it} = \alpha_i + \beta_{i1}\bar{s}_t + \beta_{i2}\bar{s}_t^e + \beta_{i3}\bar{s}_t^i + \beta_{i4}s_{it} + \varepsilon_{it+h}. \quad (19)$$

The systematic part of the regression plays the role of an error-correction term. The derivation of eq.(19) is given in the appendix. The model includes the dollar and euro factors but also includes a currency  $i$  factor,  $\bar{s}_t^i$ , the cross-sectional average of exchange rates with currency  $i$  as numeraire. The appendix shows how  $\bar{s}_t^i$  contains idiosyncratic information that can be exploited. By including it as conditioning information, the forecasts also become numeraire invariant.<sup>17</sup> Forecasts are generated by rolling regression using a 60-month lag window.

For comparison, we also generate forecasts from three other models discussed in the recent literature. One is a dollar and carry factor model, where  $\bar{s}_t^e$  in (19) is replaced by the carry counterpart  $\bar{s}_t^c$ , constructed by sorting countries by interest rates into quintiles. A second model is drawn from Engel et al. (2015), who dispense with empirical identifi-

<sup>16</sup>Drawing motivation from the present value model of exchange rates, Chen et al. (2010) and Sarno and Schmeling (2013) find evidence that today's exchange rate predicts future fundamentals. The importance of cross-sectional information has been recognized since Bilson (1981) who used seemingly unrelated regression to estimate his exchange rate equation. Frankel and Rose (1996) initiated a literature on the panel data analysis of PPP, which is surveyed by Caporale and Cerrato (2006). Cerra and Saxena (2010) employed a panel data set with a large number (98) of countries in a study of the monetary model of exchange rates.

<sup>17</sup>Empirical factors are standardized by the variance of their depreciation rates to avoid the exact multicollinearity. Since  $s_{it}$  can be perfectly correlated with  $\delta_{i1}\bar{s}_t + \delta_{i2}\bar{s}_{1,t} + \phi_i\bar{s}_t^i$ , without standardizing, the slope coefficients are not estimable in some cases. For example,  $\bar{s}_t$  in (19) is equal to  $N^{-1}\sum_{i=1}^N s_{it}/\sqrt{V(\Delta s_{it})}$  where  $V(\Delta s_{it}) = t^{-1}\sum_{\ell=1}^t (\Delta s_{i\ell} - t^{-1}\sum_{\ell=1}^t \Delta s_{i\ell})^2$ .

cation of factors and use principal components as factors  $\hat{F}_{j,t}^{pc}$ ,  $j = 1, 2$  for forecasting,<sup>18</sup>

$$s_{it+h} - s_{it} = \alpha_i + \beta_{i1}\hat{F}_{1t}^{pc} + \beta_{i2}\hat{F}_{2t}^{pc} + \beta_{i3}s_{it} + \epsilon_{it+h} \quad (20)$$

The principal components are estimated for every  $t$  and each horizon,  $h$ .

The third, is the bilateral purchasing-power parity (PPP) fundamentals model. In this model, the fundamental value of  $s_{it}$  is the PPP  $p_{it} - p_{0t}$ , where  $p_{it}$  is the log price level of country  $i$ . The model allows  $s_{it}$  to deviate from its PPP over the short and medium term, but assumes that they share a common trend so the real exchange rate is stationary and mean-reverting. The PPP-based fundamentals model is thus an error correction without the short-run dynamics,

$$s_{it+k} - s_{it} = \alpha_i + \beta_i(p_{it} - p_{0t} - s_{it}) + \epsilon_{it+k}. \quad (21)$$

If the nominal exchange rate is not weakly exogenous, the exchange rate  $s_{it}$  moves towards the PPP value  $p_{it} - p_{0t}$  over time and  $\beta_i > 0$ . This is a bilateral model in the sense that the fundamentals  $p_{it} - p_{0t}$  depend only on variables from the associated bilateral pair of countries. Exchange rate models are typically formulated in bilateral terms. Examples include monetary-based models (Mark, 1995) and Taylor Rule models augmented with the real exchange rate (Molodtsova and Papell, 2009 and Molodtsova et al., 2008, 2011). We include the PPP model because Engel et al. (2007) find that it gives the most favorable results among the fundamentals models they consider.

Forecasts are generated at one, twelve and twenty-four month horizons and for each month from 2004.1 through 2015.12. The initial rolling sample is 1999.1-2003.12 for different forecast horizons. After estimating model parameters under different horizons, the one month forecast of 2004.1 is generated using the data at 2003.12, while the twenty-four month forecast of 2004.1 is generated using the data at 2002.1. That is, we generate the same number of forecasts for each forecasting horizon. Forecast accuracy of the alternative models are compared to predictions of the driftless random walk. Theil's U statistic, the ratio of MSPE, from the model to those from the random walk, is used

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<sup>18</sup>Engel et al.(2015) considered 1,2, and 3 factor models. The forecasting ability of the 2 and 3 factor models were nearly identical and dominated that of the 1 factor model. Using quarterly data beginning in 1973, Engel et al.(2015) find that predictions of the factor-based forecasts significantly dominate random walk forecasts in mean-square error when forecasting from 1999 to 2007. We note that Engel et al.(2015), used the 'restricted' version of the forecasting which includes an extra-round of estimation. They forecasted by recursively estimating both the principal components and factor loadings which were inputted into the forecasting model  $s_{it+h} - s_{it} = \alpha_i + \beta_i\hat{s}_{it}^o + \epsilon_{it+h}$  where  $\hat{s}_{it}^o = s_{it} - \hat{\delta}_{i1}\hat{F}_{1t} - \hat{\delta}_{i2}\hat{F}_{2t}$ . Here, we use principal components in the 'unrestricted' forecasting model. This eliminates the estimation of factor loadings, which gives more accurate forecasts than the restricted forecasts.

to assess the relative accuracy of point forecasts. To evaluate whether forecasts are statistically significantly more accurate than the random walk, we use the Clark and West (2006) test of forecast accuracy. Because the regression based models (19) nest the random walk, their forecasts will have greater bias since there are more parameters to be estimated with the same amount of data. The Clark-West statistic makes an adjustment to the MSPE to account for the greater bias in the model.

To summarize, we compare the multilateral dollar-euro factor exchange rate model to the dollar-carry model, a two principal components model and the bilateral PPP fundamentals model,

$$\text{Dollar-Euro: } s_{it+h} - s_{it} = \alpha_i + \beta_{i1}s_{it} + \beta_{i2}\bar{s}_t + \beta_{i3}\bar{s}_t^e + \beta_{i4}\bar{s}_t^i + \epsilon_{i,t+h}$$

$$\text{Dollar-Carry: } s_{it+h} - s_{it} = \alpha_i + \beta_{i1}s_{it} + \beta_{i2}\bar{s}_t + \beta_{i3}\bar{s}_t^c + \beta_{i4}\bar{s}_t^i + \epsilon_{i,t+h}$$

$$\text{PC: } s_{it+h} - s_{it} = \alpha_i + \beta_{i1}\hat{F}_{1t}^{pc} + \beta_{i2}\hat{F}_{2t}^{pc} + \beta_{i3}s_{it} + \epsilon_{i,t+h}$$

$$\text{Bi-PPP: } s_{it+h} - s_{it} = \alpha_i + \beta_i(s_{it} - (p_{it} - p_{0t})) + \epsilon_{i,t+h}$$

MSPEs of the random walk and Theil's U for competing models for one-month ahead forecasts are shown in Table 8. Bolded entries indicate the model with the lowest MSPE. For these one-month ahead forecasts: Bi-PPP is almost as good as the random walk, and does better than the three factor models. But the bottom line is that none of the models can beat the random walk forecasts at the one-month horizon.

Forecasting results at the twelve-month horizon are shown in Table 9. Here, the Bi-PPP model deteriorates badly and never dominates. The three factor models perform significantly better than the random walk ( $CW > 1.28$  is significant at the 10% level and  $CW > 1.65$  is significant at the 5% level). While there are some large differences (see Theil's U for MEX, PHI) where the dollar-euro model performs much better, for the most part, the accuracy is similar across the three factor models.

Table 10 shows forecasting results at the twenty-four month horizon. Here, the Bi-PPP model is about as accurate as the random walk and the factor models are much more accurate. Again, differences across the factor models are not large, but the dollar-euro model has the most accurate point forecasts, as indicated with the lowest Theil's U, for 15 exchange rates. The dollar-carry model is most accurate for 8 exchange rates and principal components is most accurate for 4 exchange rates.

As mentioned earlier, the alternative factor candidates share a good deal of common information. This is why forecasting performance across the three factor models is similar. It is possible to forecast well even with a model that is inconsistently estimated.

This is the case with the dollar-carry model if the carry is not a common factor. Hence, the forecasting exercise should not be viewed as method to determine which candidate is the true common factor.

*Daily forecasting.* The exchange rate conditioning information is observed daily. Here, we show how the dollar-euro model is able to forecast at daily horizons. Here, we consider forecasting with daily exchange rates for the dollar-euro model and the principal components model. As with the monthly data, the random walk dominates one-step (one-day) ahead forecasts in terms of MSPE, but the dollar-euro and principal components models are more accurate at longer-horizons. The daily sample, obtained from IHS Global Insight, extends from 01/01/2013 to 03/25/2016 which gives 844 time-series observations for 25 currencies.<sup>19</sup> Forecasts generated by 60-day rolling regression and the first date forecasted was 3/25/2013.

Table 11 shows forecasting results at the one-day ahead and 4-week ahead horizons. Compared to the random walk, both models are able to forecast daily exchange rates at the 4-week horizon. At 4-weeks, the dollar-euro model dominates principal components in MSPE for 14 of 25 exchange rates. Forecasts are statistically significant with strong positive Clark-West rejections for all currencies.

## 6 Conclusion

This paper studies the source of co-movements across exchange rates. We identified a dollar factor and a euro factor as the pair of common empirical factors driving a panel of exchange rates. The carry return is not identified as a factor. Drawing on the SDF approach to the exchange rate, our identification can be interpreted as evidence that a global, a US and a euro-zone stochastic discount factor exhibit dominance in exchange rate movements. More generally, these represent global factors that have relevance for understanding asset prices in the international context. A limited exploration finds support for a risk-based interpretation of the factors. The data also reveal a geographical aspect in the way currencies load on the euro factor and a separate pattern of loading on the dollar factor by commodity currencies.

Our identification suggests empirical exchange rate modeling should incorporate multilateral dollar-euro factors. In out-of-sample forecasting, the multilateral model outper-

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<sup>19</sup>Daily observations not available for ICE. From Sept. 2011 to Jan. 2015, SWI pegged to the euro and was omitted.

forms the random walk and the bilateral purchasing-power parity fundamentals model. Forecast performance was in line with the pure statistical (principal components) factor forecasting model in terms of mean-square forecast error. The alternative multilateral model consisting of a dollar and carry factor generates similarly accurate forecasts.

The point of the forecasting analysis was not to find the best forecasting model but to demonstrate value of identification. Instead of looking at bilateral determinants on a case-by-case basis, one implication of our identification is that empirical researchers might focus on understanding the determinants the dollar and euro factors in order to understand most of the variation in any bilateral exchange rate.

Our findings suggest future directions for research. First, macro-modeling should recognize the potential importance of multi-country models for exchange rate determination. In empirical modeling, one should pay special attention to the role of the US and the euro zones on bilateral exchange rates. Consideration of multilateral factors can potentially solve the Obstfeld-Rogoff (2000) exchange rate disconnect puzzle. New directions for international asset pricing might emphasize a heightened role for global, US and euro stochastic discount factors.

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## Appendix

### Data sources for the carry, dollar and euro portfolios

Interest rate differentials used for the construction of the portfolios and portfolio excess returns are based on the forward premium (log forward minus the log spot rate). End of period spot and one-month forward NCU per USD exchange rates were sourced from Datastream. Each spot-forward pair is selected from the same underlying data source: either Barclay's Bank (BB), WM/Reuters (WMR), Thomson Reuters (TR) or the Taiwan Economic Journal (TEJ). Currencies were included in the construction of the various portfolio returns over month  $t - 1$  to  $t$  if they had forward rate at time  $t - 1$  and spot rate data at time  $t - 1$  and  $t$ : if these data were lacking then the currency was excluded. We excluded Turkey from the construction of the portfolios between February and November 2001, when the quoted 1-month forward rate is fixed, while the spot continues to vary.

The data coverage and source for each currency are as follows: Australian dollar, Dec 1984-Dec 2015, BB; Austrian Schilling, Dec 1996-Dec 1998, WMR; Belgian Franc, Feb 1985-Dec 1998, WMR; Brazilian Real, Mar 2004-Dec 2015, WMR; Canadian dollar, Dec 1984-Dec 2015, BB; Chilean Peso, Mar 2004-Dec 2015, WMR; Colombian Peso, Mar 2004-Dec 2015, WMR; Czech Koruna, Dec 1998-Dec 2015 WMR; Danish Krona, Dec 1984-Dec 1998, BB; Euro, Dec 1998-Dec2015; Finnish Markka, Dec 1996-Dec 1998, WMR; French Franc, Oct 1983-Dec 1998, BB; German Mark, Oct 1983-Dec 1998, BB; Greek Drachma, Dec 1996-Dec 1998, WMR; Hungarian Forint, Dec 1998-Dec 2015, WMR; Icelandic Krona, Mar 2004 - Dec 2015, WMR; Indian Rupee, Dec 1998 - Dec 2015, WMR; Irish Pound, Dec 1996 - Dec 1998, WMR; Israeli Shekel, Mar 2004 - Dec 2015, WMR; Italian Lira, Mar 1984 - Dec 2015, BB; Japanese Yen, Oct 1983 - Dec 2015; Korean Won, Feb 2002 - Dec 2015, WMR; Mexican Peso, Dec 1998 - Dec 2015, WMR; Dutch Guilder, Feb 1985 - Dec 1998, TR; Norwegian Krone, Dec 1984-Dec 2015, BB; NZ dollar, Dec 1984-Dec 2015, BB; Philippine Peso, Dec 1996 - Dec 2015, WMR; Polish Zloty, Dec 1998-Dec 2015, WMR; Portuguese Escudo, Dec 1996-Dec 1998, WMR; Romanian Leu, Dec 1998 - Dec 2015; South African Rand, Oct 1983-Dec 2015, BB; Singapore dollar, Dec 1984-Dec 2015, BB; Spanish Peseta, Dec 1996-Dec 1998, WMR; Swedish Krona, Dec 1984-Dec 2015, BB; Swiss Franc, Oct 1983-Dec 2015, BB; Taiwan dollar, Jan 1992-Dec 2015, TEJ; Thai Baht, Dec 1998 - Dec 2015, TR; Turkish Lira,

Dec 1998 - Feb 2001, Dec 2001 - Dec 2015, WMR; UK pound, Oct 1983 - 2015, BB.

### Derivation of the Forecasting Regression

In Section 2, we subtracted the cross sectional averages before estimating the number of the common factors to avoid the impact of the choice of the numeraire. When other currency except for the USD and Euro becomes the numeraire, the exchange rates panel must have three common factors: The USD, Euro, and the numeraire currency factors. Meanwhile when either the USD or the Euro becomes the numeraire, the exchange rates panel have only two factors. The forecasting regression should not be dependent on the choice of the numeraire. For example, the forecasting regression with NZD/USD must have the same explanatory variables with the forecasting regression with USD/NZD. To take account for this difference, we need to include all three factors in the forecasting regressions always. Rewrite the eq. (9) in the level

$$s_{it} = a_i + b_{1i}^* \bar{s}_t + b_{2i} \bar{s}_t^e + s_{it}^o, \quad (22)$$

where  $b_{1i}^* = b_{1i} - 1$ . Next, we approximate  $s_{it}^o$  as the cross sectional average of the depreciation rates with the  $i$ th numeraire currency. Note that

$$s_{jt}^i = s_{jt} - s_{it} = a_j + b_{1j}^* \bar{s}_t + b_{2j} \bar{s}_t^e + s_{jt}^o - s_{it}^o.$$

Hence the cross sectional average of  $s_{jt}^i$  becomes

$$N^{-1} \sum_{j \neq i}^N s_{jt}^i = \bar{a} + \bar{b}_1^* \bar{s}_t + \bar{b}_2 \bar{s}_t^e + N^{-1} \sum_{j \neq i}^N s_{jt}^o - s_{it}^o.$$

Then the idiosyncratic component,  $s_{it}^o$ , can be written as

$$s_{it}^o = N^{-1} \sum_{j \neq i}^N s_{jt}^i - \bar{a} - \bar{b}_1^* \bar{s}_t - \bar{b}_2 \bar{s}_t^e + O_p(N^{-1/2}). \quad (23)$$

Plugging the eq. (23) into (22) leads to

$$s_{it} = a_i^+ + b_{1i}^+ \bar{s}_t + b_{2i}^+ \bar{s}_t^e + \bar{s}_t^i + v_{it},$$

where  $v_{it}$  is the approximation error,  $b_{1i}^+ = b_{1i}^* - \bar{b}_1^*$ ,  $b_{2i}^+ = b_{2i} - \bar{b}_2$  and  $a_i^+ = a_i - \bar{a}$ . We assume that this approximation error,  $v_{it}$ , is stationary. Then there exists the following restrictive error correction model (ECM).

$$s_{it+1} - s_{it} = \alpha_i + \lambda_i (s_{it} - b_{1i}^+ \bar{s}_t - b_{2i}^+ \bar{s}_t^e - \bar{s}_t^i) + \varepsilon_{it+1}.$$

To provide more flexibility, we consider the following unrestricted version of the ECM for the  $h$ -period ahead forecasts.

$$s_{it+h} - s_{it} = \alpha_i + \beta_{i1}s_{it} + \beta_{i2}\bar{s}_t + \beta_{i3}\bar{s}_t^e + \beta_{i4}\bar{s}_t^i + \varepsilon_{i,t+h}. \quad (24)$$

For some exchange rates,  $\varepsilon_{it}$  is nearly zero due to near exact multicollinearity among explanatory variables. To avoid this problem, empirical factors are standardized by the variance of their depreciation rates. Since  $s_{it}$  can be perfectly correlated with  $\delta_{i1}\bar{s}_t + \delta_{i2}\bar{s}_{1,t} + \phi_i\bar{s}_t^i$ , without standardizing, the slope coefficients are not estimable in some cases. For example,  $\bar{s}_t$  in (19) is equal to  $N^{-1} \sum_{i=1}^N s_{it} / \sqrt{V(\Delta s_{it})}$  where  $V(\Delta s_{it}) = t^{-1} \sum_{\ell=1}^t (\Delta s_{i\ell} - t^{-1} \sum_{\ell=1}^t \Delta s_{i\ell})^2$ . Also note that when  $i = \text{euro}$ ,  $\bar{s}_t^e = \bar{s}_t^i$ . Hence we didn't include the local currency factor in the case of Euro/USD.

### Clark-West test

Interpreting MSPE as an estimator of the true (or population) MSPE of the model, Clark and West (2007) argue that this leads to greater bias in the MSPE of larger models than smaller models due to the fact that the larger model has more parameters to be estimated with the same amount of data. Clark and West (2007) therefore propose an adjusted MSPE to account for this bias. This adjustment is particularly appropriate when using out-of-sample loss as a basis for model evaluation (as it is in the current application). To test whether model  $a$  has a lower MSPE than model  $b$  we employ Clark and West's (2007) test of equal MSPEs from nested models.

The Clark and West test of the null hypothesis that  $\ddot{U}_h^{(a,b)} < 1$  is based on testing whether the mean of

$$J_{i,s,h}^{(a,b)} = (\hat{s}_{i,s+h}^a - s_{i,s+h})^2 - (\hat{s}_{i,s+h}^b - s_{i,s+h})^2 - P^{-1} \sum_{s=1}^P (\hat{s}_{i,s+h}^b - s_{i,s+h})^2$$

is less than zero. Clark and West (2007) show that

$$P^{-1} \sum_{s=1}^P J_{i,s,h}^{(a,b)} / \sqrt{V \left( P^{-1} \sum_{s=1}^P J_{i,s,h}^{(a,b)} \right)} \stackrel{a}{\sim} N(0, 1)$$

under the null hypothesis that  $\ddot{U}_h^{(a,b)} = 1$ . To estimate  $V \left( J_{i,h}^{(a,b)} \right)$  they suggest using the Newey-West estimator. We use the estimator with the truncation lag set to be  $h - 1$  since the forecast errors overlap  $h - 1$  periods.

Table 1: Top Ten Currencies Ranked By Global Foreign Exchange Market Volume

Percentage Shares Of Average Daily Volume							
	1998	2001	2004	2007	2010	2013	Average
US dollar	86.8	89.9	88	85.6	84.9	87	87.0
Euro	...	37.9	37.4	37	39.1	33.4	37.0
Yen	21.7	23.5	20.8	17.2	19	23	20.9
Pound	11	13	16.5	14.9	12.9	11.8	13.4
Swiss Franc	7.1	6	6	6.8	6.3	5.2	6.2
Australian dollar	3	4.3	6	6.6	7.6	8.6	6.0
Canadian dollar	3.5	4.5	4.2	4.3	5.3	4.6	4.4
Swedish Krona	0.3	2.5	2.2	2.7	2.2	1.8	2.0
Norwegian Krone	0.2	1.5	1.4	2.1	1.3	1.4	1.3
Other	65.4	14.7	15.7	20.1	19	21.8	20.0
Total	200	200	200	200	200	200	200

Table 2: Frequency of Common Factor Detection in Post-Euro Residual Panel. Conditional on Dollar Factor

Numeraire	Candidate Factors											
	Selected Currencies			All Countries Conditional Carry			Developed Countries Conditional Carry			Developed Countries Unconditional Carry		
	EUR	JPN	SWI	Quint.	Quart.	Tert.	Quint.	Quart.	Tert.	Quint.	Quart.	Tert.
USA	1	0	0	0	0	0	0	0	0	0	0	0
AUS	1	0	0	0	0	0	0	0	0	0	0	0
BRA	1	0	0	0	0	0	0	0	0	0	0	0
CAN	1	0	0	0	0	0	0	0	0	0	0	0
CHI	1	0	0	0	0	0	0	0	0	0	0	0
COL	1	0	0	0	0	0	0	0	0	0	0	0
CZE	1	0	0.38	0	0	0	0	0	0	0	0	0
EUR	1	0	0.83	0	0	0	0	0	0	0	0	0
GBR	1	0	0	0	0	0	0	0	0	0	0	0
HUN	1	0	0	0	0	0	0	0	0	0	0	0
ICE	1	0	0	0	0	0	0	0	0	0	0	0
IND	1	0	0	0	0	0	0	0	0	0	0	0
ISR	1	0	0	0	0	0	0	0	0	0	0	0
JPN	1	0	0	0	0	0	0	0	0	0	0	0
KOR	1	0	0	0	0	0	0	0	0	0	0	0
MEX	1	0	0	0	0	0	0	0	0	0	0	0
NOR	1	0	0	0	0	0	0	0	0	0	0	0
NZL	1	0	0	0	0	0	0	0	0	0	0	0
PHL	1	0	0	0	0	0	0	0	0	0	0	0
POL	1	0	0	0	0	0	0	0	0	0	0	0
ROM	1	0	0	0	0	0	0	0	0	0	0	0
RSA	1	0	0	0	0	0	0	0	0	0	0	0
SIN	1	0	0	0	0	0	0	0	0	0	0	0
SWE	1	0	0	0	0	0	0	0	0	0	0	0
SWI	1	0	0	0	0	0	0	0	0	0	0	0
THA	1	0	0	0	0	0	0	0	0	0	0	0
TUR	1	0	0	0	0	0	0	0	0	0	0	0
TWN	1	0	0	0	0	0	0	0	0	0	0	0

Note: For each numeraire currency, the identification procedure is applied to 47 recursively backdated samples. Every sample ends 2015.12. The first sample begins 2002.11 The last sample begins 1999.02. Table shows frequency with which a common factor is detected in the residual panel out of 47 trials.

Table 3: Frequency of Common Factor Detection in Pre-Euro Residual Panel. Conditional on Dollar Factor

Numer- aire	Candidate Factors								
	Selected Currencies			Developed Countries Conditional Carry			Developed Countries Conditional Carry		
	GER	JPN	SWI	Quint.	Quart.	Tert.	Quint.	Quart.	Tert.
USA	1	0	0	0	0	0	0	0	0
AUS	1	0	0	0	0	0	0	0	0
CAN	1	0	0	0	0	0	0	0	0
GBR	0	0	0	0	0	0	0	0	0
GER	1	0	0	0	0	0	0	0	0
ICE	0.15	0	0	0	0	0	0	0	0
ISR	0.65	0	0	0	0	0	0	0	0
JAP	0.89	0	0	0	0	0	0	0	0
KOR	1	0	0	0	0	0	0	0	0
NOR	0	0	0	0	0	0	0	0	0
NZL	0.85	0	0	0	0	0	0	0	0
PHL	1	0	0	0	0	0	0	0	0
RSA	1	0	0	0	0	0	0	0	0
SIN	0.85	0	0	0	0	0	0	0	0
SWE	0	0	0	0	0	0	0	0	0
TWN	1	0	0	0	0	0	0	0	0
TWN	1	0	0	0	0	0	0	0	0

See notes to Table 2.

Table 4: Factor Identification by Verdelhan's Method over the Full Sample.  $R^2$  and t-ratios on coefficients in eqs. (11) and (12).

	Equation (11)			Equation (12)			
	$t_{\beta_3}$	$t_{\beta_4}$	$\bar{R}^2$	$t_{\beta_3}$	$t_{\beta_4}$	$t_{\beta_5}$	$\bar{R}^2$
AUS	1.365	-0.276	0.774	-0.198	-0.22	<b>2.782</b>	0.78
BEL	<b>-5.992</b>	<b>2.122</b>	0.934	-0.43	0.506	<b>-21.22</b>	0.984
BRA	-0.225	1.617	0.536	-0.645	0.498	<b>5.932</b>	0.604
CAN	<b>7.176</b>	<b>-3.669</b>	0.342	<b>3.391</b>	<b>-3.927</b>	<b>5.176</b>	0.374
CHI	1.831	-0.406	0.467	0.673	-0.594	<b>2.379</b>	0.481
COL	1.476	0.562	0.478	-0.693	1.052	<b>5.219</b>	0.549
CZE	<b>-5.81</b>	1.576	0.683	-1.258	1.91	<b>-11.44</b>	0.806
DEN	<b>-4.365</b>	-0.12	0.916	1.339	<b>-3.117</b>	<b>-16.51</b>	0.959
EUR	<b>-7.299</b>	-0.399	0.757	0.676	-0.374	<b>-187.5</b>	0.998
FRA	<b>-4.296</b>	<b>2.048</b>	0.904	1.319	-0.039	<b>-16.51</b>	0.957
GBR	<b>-2.771</b>	<b>2.679</b>	0.576	-1.305	1.526	-1.943	0.582
GER	<b>-4.75</b>	1.189	0.923	<b>-4.246</b>	1.112	$\infty$	1
HUN	<b>-2.599</b>	1.194	0.726	-0.252	0.924	<b>-7.28</b>	0.784
ICE	-0.741	1.211	0.333	-0.896	0.853	1.02	0.336
IND	-0.756	2.875	0.412	<b>-2.433</b>	<b>4.558</b>	<b>2.981</b>	0.444
ISR	<b>-2.321</b>	0.171	0.409	-1.068	0.253	-0.299	0.409
ITA	<b>-2.381</b>	<b>2.365</b>	0.768	-1.032	1.924	-1.232	0.771
JPN	<b>-4.768</b>	0.383	0.287	<b>-4.523</b>	1.532	1.314	0.293
KOR	0.755	-0.243	0.555	-0.818	<b>-2.508</b>	<b>2.699</b>	0.567
MEX	<b>2.890</b>	-0.075	0.345	1.241	0.729	<b>6.156</b>	0.443
NET	<b>-6.081</b>	1.367	0.924	0.481	-0.443	<b>-59.65</b>	0.986
NOR	-0.052	1.112	0.853	<b>2.256</b>	0.74	<b>-5.113</b>	0.872
NZL	1.093	0.97	0.386	-1.673	1.284	<b>5.226</b>	0.417
PHI	-0.755	1.457	0.23	<b>-2.566</b>	<b>2.037</b>	<b>4.199</b>	0.282
POL	<b>-2.145</b>	<b>2.007</b>	0.713	-1.044	1.514	-1.609	0.718
ROM	<b>-2.430</b>	0.977	0.703	-0.124	0.753	<b>-6.19</b>	0.787
RSA	1.570	-0.068	0.381	-1.721	-0.176	<b>6.549</b>	0.428
SIN	-1.143	-0.686	0.5	<b>-2.213</b>	-0.91	<b>4.437</b>	0.53
SWE	<b>-5.168</b>	<b>6.097</b>	0.758	-0.963	<b>4.605</b>	<b>-6.305</b>	0.779
SWI	<b>-6.185</b>	1.899	0.715	<b>-2.376</b>	<b>2.696</b>	<b>-14.08</b>	0.796
THA	-1.386	-0.251	0.34	<b>-3.625</b>	-0.178	<b>4.532</b>	0.4
TUR	<b>2.674</b>	0.205	0.445	1.683	-0.281	<b>4.991</b>	0.495
TWN	-1.724	<b>2.142</b>	0.35	<b>-4.885</b>	<b>2.666</b>	<b>5.415</b>	0.402

Note: Bold indicates significance at the 5% level. We use any observations available from 1983.10–2015.12. Carry return formed by sorting countries into quintiles.

Table 5: Factor Identification by Verdelhan's Method over the Euro Epoch Sample.  $R^2$  and t-ratios on coefficients in eqs. (11) and (12).

	Equation (11)			Equation (12)			
	$t_{\beta_3}$	$t_{\beta_4}$	$\bar{R}^2$	$t_{\beta_3}$	$t_{\beta_4}$	$t_{\beta_5}$	$\bar{R}^2$
AUS	1.39	-0.212	0.777	0.338	-0.148	<b>2.454</b>	0.783
BRA	-0.231	1.61	0.536	-0.843	1.161	<b>5.417</b>	0.604
CAN	<b>3.238</b>	-1.733	0.51	1.463	-1.635	<b>2.644</b>	0.52
CHI	1.855	-0.464	0.474	0.914	-0.600	<b>2.268</b>	0.487
COL	1.531	0.587	0.478	-0.736	0.764	<b>5.468</b>	0.549
CZE	<b>-6.135</b>	1.245	0.688	-0.883	1.790	<b>-12.19</b>	0.812
EUR	<b>-7.304</b>	-0.364	0.758	<b>4.072</b>	0.752	$\infty$	1
GBR	0.723	0.636	0.491	-1.478	0.102	<b>4.726</b>	0.535
HUN	<b>-2.570</b>	1.222	0.726	-0.591	1.198	<b>-7.32</b>	0.785
ICE	-0.705	1.212	0.321	-0.847	1.215	0.567	0.322
IND	-0.744	<b>2.848</b>	0.412	-1.914	<b>2.931</b>	<b>3.406</b>	0.445
ISR	<b>-1.997</b>	0.663	0.321	<b>-2.631</b>	0.764	1.823	0.331
JPN	<b>-3.649</b>	0.134	0.196	<b>-4.324</b>	0.012	<b>2.333</b>	0.22
KOR	<b>-4.494</b>	0.273	0.691	<b>-6.291</b>	0.247	<b>4.621</b>	0.713
MEX	<b>3.074</b>	-1.042	0.415	0.444	0.082	<b>6.803</b>	0.516
NOR	<b>-3.566</b>	1.335	0.667	-0.147	1.09	<b>-6.849</b>	0.713
NZL	1.065	-1.386	0.63	0.710	-1.422	1.163	0.632
PHI	1.368	-1.814	0.285	0.062	-1.506	<b>2.835</b>	0.317
POL	<b>-2.146</b>	<b>1.969</b>	0.715	-1.141	1.801	-1.662	0.719
ROM	<b>-2.425</b>	0.974	0.705	0.513	0.657	<b>-7.103</b>	0.788
RSA	1.315	-0.182	0.467	-0.525	-0.329	<b>4.014</b>	0.503
SIN	<b>-4.665</b>	<b>3.165</b>	0.789	<b>-2.062</b>	<b>2.901</b>	<b>-8.600</b>	0.827
SWE	<b>-4.743</b>	<b>2.054</b>	0.598	-1.783	<b>2.629</b>	<b>-10.07</b>	0.707
SWI	<b>-2.969</b>	0.380	0.478	<b>-5.182</b>	0.588	<b>4.580</b>	0.521
THA	-1.407	-0.256	0.340	<b>-3.189</b>	-0.509	<b>4.400</b>	0.400
TUR	<b>4.555</b>	-0.263	0.446	<b>2.436</b>	-1.116	<b>5.337</b>	0.496
TWN	<b>-2.200</b>	<b>-3.187</b>	0.550	-0.591	<b>-3.421</b>	<b>-2.322</b>	0.565

Note: Bold indicates significance at the 5% level. Euro-epoch sample. Carry return formed by sorting countries into quintiles

Table 6: Identified Factor Structure during Euro Epoch

		$\Delta \tilde{s}_{it} = \tilde{\delta}_{i1} \Delta \bar{s}_t + \tilde{\delta}_{i2} \Delta \bar{s}_t^e + \Delta s_{it}^o$				
		Dollar		Euro		$R^2$
		$\tilde{\delta}_{i1}$	t-ratio	$\tilde{\delta}_{i2}$	t-ratio	
Western Europe	GBR	-0.278	-4.950	-0.252	-3.766	0.137
	ICE	0.028	0.237	-0.173	-1.211	0.015
	NOR	0.147	2.926	-0.474	-7.895	0.235
	SWE	0.213	5.407	-0.555	-11.834	0.408
	SWI	-0.137	-2.800	-0.741	-12.658	0.370
Emerging Europe	CZE	0.161	3.181	-0.88	-14.547	0.537
	HUN	0.519	7.827	-0.658	-8.312	0.458
	POL	0.532	6.540	-0.212	-2.184	0.262
	ROM	0.111	1.214	-0.461	-4.228	0.156
Common Wealth	AUS	0.501	9.446	0.195	3.091	0.288
	CAN	-0.111	-2.302	0.238	4.158	0.084
	NZL	0.410	6.167	0.051	0.649	0.124
	RSA	0.537	4.365	0.492	3.350	0.131
Mid East	ISR	-0.408	-6.487	0.039	0.519	0.186
TUR	0.383	2.631	0.678	3.903	0.114	
Asia	IND	-0.343	-6.724	0.266	4.369	0.263
	JPN	-0.827	-8.782	-0.16	-1.421	0.311
	KOR	0.086	1.281	0.346	4.330	0.077
	PHI	-0.519	-9.372	0.176	2.675	0.384
	SIN	-0.387	-13.726	0.043	1.266	0.469
	THA	-0.503	-10.701	0.151	2.690	0.404
	TWN	-0.571	-17.283	0.07	1.772	0.621
Latin America	BRA	0.548	4.582	1.071	7.504	0.225
	CHI	-0.068	-0.777	0.373	3.576	0.077
	COL	0.151	1.754	0.718	6.979	0.199
	MEX	-0.141	-2.106	0.623	7.779	0.278

Note: Estimated over the euro-epoch sample.

Table 7: Risk-Based Interpretation of Dollar and Euro Factors

A. Return Characteristics							
	Portfolios Sorted by Dollar Loadings			Portfolios Sorted by Euro Loadings			
	$P_1$	$P_2$	$P_3$	$P_1$	$P_2$	$P_3$	
	<u>Simple excess return</u>						
mean	-3.267	0.955	3.560	-0.181	0.200	3.652	
std.dev.	28.414	29.392	35.092	18.280	33.369	28.953	
	<u>Depreciation rate</u>						
mean	1.041	1.484	0.987	0.385	0.279	1.386	
std.dev.	16.241	28.687	34.567	12.215	25.796	28.411	
	<u>Interest differential</u>						
mean	-2.227	2.439	4.546	0.203	0.478	5.038	
std.dev.	22.805	3.5557	3.980	12.560	19.963	2.952	
	<u>Aggregate conditional portfolio excess return</u>						
	<u>Sorted by Dollar Load</u>			<u>Sorted by Euro Load</u>			
mean	4.097			4.590			
std.dev.	26.491			21.057			
Sharpe	0.155			0.218			
B. Two-Factor Beta-Risk Model							
	<u>First Stage Betas</u>						
	$\beta_1$	$\beta_2$	$\beta_3$	$\beta_4$	$\beta_5$	$\beta_6$	
Dollar-Risk	0.194	0.928	1.175	-0.438	-0.278	-0.114	
Euro-Risk	-0.085	-0.505	0.0068	0.228	0.521	1.075	
	<u>Second Stage</u>						
	$\lambda_U$	t-ratio	$\lambda_E$	t-ratio	$R^2$	$\chi^2_{10}$	p-value
	2.884	1.221	3.928	1.862	0.830	5.221	0.345

Note: Estimated over the euro-epoch sample.

Table 8: Forecasting at One-Month Horizon

	Random	Dollar-		Dollar-		Principal		Bi-PPP	
	Walk	Euro		Carry		Components			
	MSPE	U	$t_{CW}$	U	$t_{CW}$	U	$t_{CW}$	U	$t_{CW}$
AUS	<b>1.415</b>	1.236	0.306	1.099	2.573	1.042	1.436	1.004	1.163
BRA	<b>2.009</b>	1.267	0.443	1.062	2.286	1.190	0.641	1.021	0.764
CAN	0.829	1.192	-0.649	<b>0.965</b>	3.282	1.110	-0.527	1.045	-0.909
CHI	1.186	1.169	-1.302	1.027	1.813	<b>1.000</b>	1.358	1.036	-1.172
COL	<b>1.571</b>	1.210	-1.347	1.159	0.872	1.127	-0.453	1.032	-0.655
CZE	<b>1.405</b>	1.189	-0.416	1.105	1.578	1.153	0.629	1.021	0.223
EUR	<b>0.910</b>	1.162	-1.201	1.173	-0.301	1.117	-1.068	1.016	-0.030
GBR	<b>0.637</b>	1.193	0.074	1.140	0.966	1.148	0.167	1.018	0.253
HUN	<b>2.125</b>	1.174	-0.818	1.157	0.058	1.066	0.956	1.033	-0.922
ICE	<b>1.924</b>	1.310	-0.352	1.367	-0.153	1.267	-0.623	1.051	-0.558
IND	0.649	1.155	-0.267	1.046	2.345	1.094	-0.716	<b>0.997</b>	1.074
ISR	<b>0.585</b>	1.230	-0.002	1.363	0.652	1.259	0.372	1.023	0.163
JPN	<b>0.721</b>	1.146	0.300	1.144	0.689	1.143	-0.667	1.056	-0.577
KOR	<b>1.200</b>	1.329	-0.496	1.288	-0.012	1.220	-0.863	1.033	-1.499
MEX	<b>0.859</b>	1.090	0.871	1.124	2.392	1.183	-0.523	1.025	-0.137
NOR	<b>1.202</b>	1.198	-1.494	1.079	0.966	1.078	-0.025	1.025	-0.268
NZL	1.566	1.176	-0.757	1.157	0.709	1.138	-1.434	<b>0.991</b>	1.386
PHI	<b>0.285</b>	1.336	0.576	1.049	1.733	1.087	0.395	1.056	-0.420
POL	<b>1.975</b>	1.260	-0.775	1.173	0.824	1.187	0.269	1.004	1.109
ROM	<b>1.341</b>	1.151	-0.728	1.052	1.242	1.078	-0.461	1.045	-0.936
RSA	2.242	1.081	0.522	<b>0.988</b>	3.801	1.148	-0.339	0.998	1.594
SIN	<b>0.291</b>	1.166	-0.384	1.158	0.580	1.147	-0.445	1.057	-0.355
SWE	<b>1.197</b>	1.294	-1.508	1.169	0.102	1.111	-0.213	1.011	1.150
SWI	<b>0.966</b>	1.152	-0.790	1.229	0.525	1.176	-1.429	1.022	0.752
THA	<b>0.265</b>	1.143	0.527	1.086	0.869	1.058	0.742	1.006	1.370
TUR	<b>1.638</b>	1.256	0.685	1.078	1.930	1.190	0.396	1.040	0.478
TWN	<b>0.207</b>	1.195	0.282	1.106	1.485	1.020	1.280	1.026	-0.635

Note: U is the MSPE of the model in question divided by the MSPE of the random walk.  $t_{CW}$  is the t-ratio for the Clark-West (2002) statistic, and is significant at the 10% level if it exceeds 1.28.

Table 9: Forecasting at Twelve-Month Horizon

	Random	Dollar-		Dollar-		Principal		Bi-PPP	
	Walk	Euro		Carry		Components			
	MSPE	U	$t_{CW}$	U	$t_{CW}$	U	$t_{CW}$	U	$t_{CW}$
AUS	20.676	0.455	3.507	0.497	3.372	<b>0.356</b>	3.727	1.000	1.893
BRA	33.094	<b>0.447</b>	5.131	0.469	5.289	0.469	5.081	0.987	1.372
CAN	9.649	0.525	3.894	0.490	4.038	<b>0.424</b>	4.121	0.900	2.234
CHI	14.120	0.506	3.920	0.540	3.698	<b>0.488</b>	4.329	1.215	-0.410
COL	21.226	0.546	3.994	0.555	4.066	<b>0.480</b>	3.950	1.033	0.784
CZE	16.581	0.485	3.890	0.516	4.394	<b>0.322</b>	5.517	0.822	2.886
EUR	10.410	0.484	4.990	0.508	5.219	<b>0.464</b>	5.220	0.986	1.984
GBR	10.009	<b>0.399</b>	2.303	0.524	2.339	0.497	2.175	1.110	1.093
HUN	18.811	0.457	4.542	0.545	4.140	<b>0.453</b>	4.226	0.947	2.181
ICE	37.972	<b>0.517</b>	2.395	0.609	2.315	0.764	1.829	1.080	1.497
IND	9.367	<b>0.346</b>	4.557	0.360	4.424	0.385	4.361	0.836	2.856
ISR	7.573	0.478	4.098	0.495	4.070	<b>0.443</b>	4.454	0.900	2.090
JPN	11.380	<b>0.457</b>	5.585	0.466	4.888	0.791	3.796	0.866	2.682
KOR	14.317	0.366	2.242	<b>0.365</b>	2.242	0.464	2.305	1.160	-0.033
MEX	11.209	<b>0.374</b>	2.778	0.503	2.379	0.682	2.552	1.005	1.125
NOR	16.354	0.443	4.137	0.480	3.818	<b>0.323</b>	3.993	0.912	2.146
NZL	20.062	0.420	3.292	0.445	3.092	<b>0.385</b>	3.259	1.094	1.398
PHI	4.877	<b>0.599</b>	3.451	0.723	3.224	0.794	2.960	1.177	0.512
POL	24.925	0.459	3.329	<b>0.443</b>	3.247	0.457	3.095	0.933	1.419
ROM	16.389	<b>0.309</b>	3.967	0.379	3.685	0.354	3.628	1.188	0.631
RSA	22.181	0.402	4.169	<b>0.380</b>	4.544	0.445	4.069	1.141	0.550
SIN	3.540	0.394	3.892	0.365	4.950	<b>0.347</b>	4.363	0.811	2.704
SWE	16.125	0.460	3.839	0.518	3.438	<b>0.312</b>	3.710	1.007	1.796
SWI	8.502	0.554	3.094	<b>0.512</b>	3.558	0.552	3.160	0.950	2.185
THA	4.041	0.551	5.241	0.617	4.820	<b>0.531</b>	5.035	0.834	2.358
TUR	20.188	<b>0.566</b>	4.703	0.584	4.623	0.651	4.418	1.243	1.281
TWN	2.206	0.479	4.361	0.501	4.371	<b>0.449</b>	3.628	1.124	0.299

Note: U is the MSPE of the model in question divided by the MSPE of the random walk.  $t_{CW}$  is the t-ratio for the Clark-West (2002) statistic, and is significant at the 10% level if it exceeds 1.28.

Table 10: Forecasting at Twenty-Four Month Horizon

	Random	Dollar-		Dollar-		Principal		Bi-PPP	
	Walk	Euro		Carry		Components			
	MSPE	U	$t_{CW}$	U	$t_{CW}$	U	$t_{CW}$	U	$t_{CW}$
AUS	36.635	<b>0.227</b>	4.368	0.240	4.588	0.291	4.328	0.955	3.272
BRA	58.283	<b>0.208</b>	6.585	0.210	7.028	0.256	6.439	0.915	2.622
CAN	17.880	0.230	5.304	<b>0.206</b>	5.644	0.223	5.899	0.712	3.780
CHI	23.530	0.566	5.467	<b>0.290</b>	6.004	0.721	5.840	1.264	0.809
COL	30.189	<b>0.318</b>	5.184	0.411	5.420	0.460	4.928	0.969	2.084
CZE	30.290	0.201	5.023	0.215	5.215	<b>0.174</b>	4.979	0.571	4.628
EUR	17.548	<b>0.228</b>	3.404	0.233	3.452	0.239	3.877	0.970	2.685
GBR	17.536	<b>0.191</b>	4.094	0.223	4.133	0.313	3.941	1.100	2.241
HUN	28.735	<b>0.270</b>	4.813	0.281	4.949	0.316	4.235	0.913	3.135
ICE	75.657	0.226	2.439	<b>0.195</b>	2.508	0.288	2.392	0.926	2.137
IND	15.526	<b>0.244</b>	4.715	0.294	4.347	0.313	4.624	0.770	3.214
ISR	9.681	<b>0.349</b>	4.010	0.354	3.949	0.442	3.411	1.070	1.373
JPN	30.351	<b>0.093</b>	6.275	0.107	6.272	0.239	6.837	0.339	5.699
KOR	24.046	<b>0.246</b>	3.723	0.257	3.556	0.335	3.833	1.178	1.053
MEX	15.515	<b>0.275</b>	4.186	0.332	4.201	0.396	3.879	1.021	1.838
NOR	22.219	0.341	5.320	0.365	5.477	<b>0.329</b>	4.879	0.858	3.131
NZL	32.739	0.312	4.002	<b>0.305</b>	3.922	0.377	3.538	1.027	2.396
PHI	9.555	<b>0.182</b>	4.508	0.241	4.407	0.397	4.930	1.080	2.034
POL	32.642	0.358	5.175	0.402	5.302	<b>0.312</b>	5.006	0.829	2.459
ROM	25.046	<b>0.297</b>	4.452	0.343	4.722	0.380	4.394	1.355	1.626
RSA	60.925	<b>0.150</b>	4.634	0.164	4.810	0.199	4.140	1.162	1.315
SIN	7.226	<b>0.141</b>	4.780	0.164	5.430	0.207	4.456	0.630	4.862
SWE	25.852	0.228	4.746	<b>0.220</b>	4.867	0.351	4.791	1.106	1.752
SWI	15.920	0.197	4.491	0.224	4.727	<b>0.149</b>	4.978	0.855	3.625
THA	8.333	0.180	4.265	<b>0.168</b>	4.386	0.349	3.572	0.758	3.699
TUR	30.431	0.308	5.138	<b>0.300</b>	5.284	0.363	5.321	1.606	2.172
TWN	3.482	0.275	3.999	<b>0.208</b>	4.683	0.260	3.822	1.211	1.029

Note: U is the MSPE of the model in question divided by the MSPE of the random walk.  $t_{CW}$  is the t-ratio for the Clark-West (2002) statistic, and is significant at the 10% level if it exceeds 1.28.

Table 11: Forecasting at Daily Horizons

	One-Day Ahead					Four-Weeks Ahead				
	Random	Dollar-		Principal		Random	Dollar-		Principal	
	Walk	Euro		Components		Walk	Euro		Components	
	MSPE	U	$t_{CW}$	U	$t_{CW}$	MSPE	U	$t_{CW}$	U	$t_{CW}$
AUS	<b>0.041</b>	1.118	-1.818	1.141	-1.009	0.871	<b>0.256</b>	9.344	0.259	9.125
BRA	<b>0.087</b>	1.108	-0.364	1.143	-1.441	2.366	0.245	7.504	<b>0.244</b>	7.659
CAN	<b>0.021</b>	1.107	0.654	1.142	0.771	0.555	<b>0.236</b>	8.083	0.329	7.366
CHI	<b>0.030</b>	1.115	-0.532	1.123	-1.266	0.710	0.278	10.140	<b>0.276</b>	10.189
COL	<b>0.057</b>	1.107	0.463	1.099	0.330	2.020	<b>0.226</b>	7.921	0.274	7.653
CZE	<b>0.037</b>	1.128	-1.095	1.129	-0.436	0.718	0.327	7.194	<b>0.312</b>	7.553
EUR	<b>0.029</b>	1.094	-1.179	1.154	-0.223	0.555	0.319	7.309	<b>0.251</b>	7.220
GBR	<b>0.020</b>	1.114	-1.137	1.125	-1.607	0.383	<b>0.253</b>	8.800	0.290	8.395
HUN	<b>0.045</b>	1.129	-1.056	1.117	0.912	0.712	0.319	7.632	<b>0.307</b>	6.939
IND	<b>0.026</b>	1.129	0.758	1.182	0.027	0.604	0.308	5.289	<b>0.304</b>	5.251
ISR	<b>0.017</b>	1.132	-1.213	1.087	0.341	0.321	<b>0.264</b>	8.987	0.308	8.910
JPN	<b>0.032</b>	1.115	0.004	1.064	2.442	0.705	<b>0.265</b>	6.961	0.303	6.808
KOR	<b>0.023</b>	1.111	-0.296	1.118	0.386	0.457	<b>0.284</b>	10.068	0.310	8.871
MEX	<b>0.034</b>	1.124	-0.597	1.128	-0.015	0.757	<b>0.264</b>	7.679	0.321	7.430
NOR	<b>0.050</b>	1.147	-0.409	1.156	-0.487	0.949	<b>0.249</b>	7.767	0.300	7.605
NZL	<b>0.048</b>	1.141	-0.931	1.100	0.851	0.945	<b>0.247</b>	9.487	0.276	9.708
PHI	<b>0.009</b>	1.071	2.378	1.125	-0.279	0.205	<b>0.303</b>	6.700	0.332	6.941
POL	<b>0.040</b>	1.149	-1.234	1.137	0.159	0.745	0.335	8.125	<b>0.317</b>	7.877
ROM	<b>0.033</b>	1.123	-1.211	1.131	0.741	0.609	0.304	7.662	<b>0.278</b>	7.167
RSA	<b>0.073</b>	1.185	-1.379	1.182	-1.602	1.344	0.299	8.707	<b>0.290</b>	8.007
SIN	<b>0.011</b>	1.125	-1.223	1.118	-0.308	0.200	<b>0.292</b>	11.391	0.298	10.933
SWE	<b>0.037</b>	1.124	0.411	1.132	1.330	0.615	<b>0.285</b>	8.544	0.297	8.112
THA	<b>0.009</b>	1.077	2.358	1.107	1.416	0.263	0.304	8.002	<b>0.271</b>	8.182
TUR	<b>0.046</b>	1.164	-1.105	1.168	0.050	1.122	<b>0.261</b>	9.402	0.307	8.614
TWN	<b>0.009</b>	1.089	1.116	1.124	0.582	0.150	0.265	7.810	<b>0.255</b>	7.268

Note U is the MSPE of the model in question divided by the MSPE of the random walk.  $t_{CW}$  is the t-ratio for the Clark-West (2002) statistic, and is significant at the 10% level if it exceeds 1.28. In some cases, regressors were perfectly collinear even after standardizing the observations. Hence, local currency factor omitted in the forecasting regression and observations are not standardized.

Figure 1: Dollar Factor and Principal Components

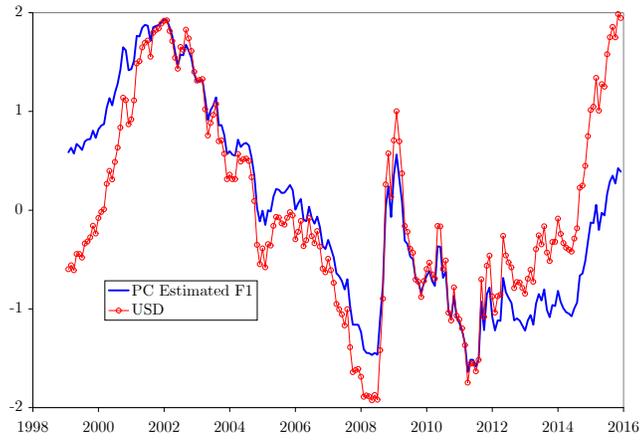


Figure 2: Euro Factor and Principal Components

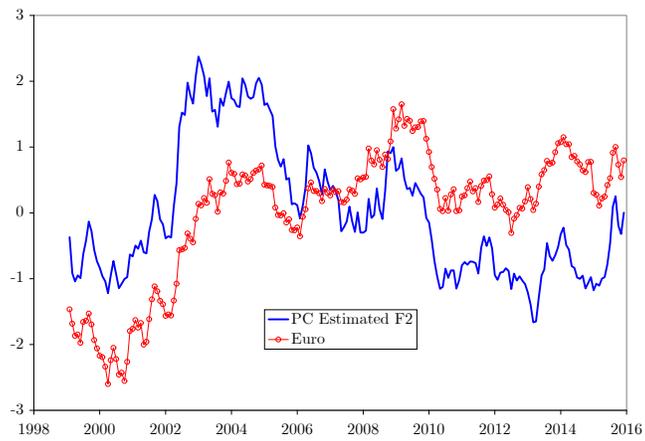


Figure 3: Actual and Predicted Average Excess Returns

