# Emerging Market Currency Excess Returns

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**Abstract**

We consider the excess return from 20 internationally tradable emerging market (EM) currencies against the U.S. dollar. It has two contributions. First, we document stylized facts about EM currencies. EM currencies have provided significant equity-like excess returns against major currencies, but with low volatility. Picking EM currencies with a relatively high forward premium raises the portfolio return substantially. Second, our calculation incorporates institutional features of the foreign exchange market such as lags in settling spot contracts, FX swaps, and bid/offer spreads. Transactions costs arising from bid/offer spreads are less than one-fifth of what is typically presumed in the literature.

*Keywords:* excess return, emerging market currencies, forward premium, FX swaps, bid/offer spreads

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We examine the foreign exchange excess return (the difference between the forward exchange rate and the spot rate at maturity) from taking long positions in 20 internationally tradable EM (emerging market) currencies for USD (the U.S. dollar) investors. Our paper has two contributions. First, it contributes to the vast literature on the failure of Uncovered Interest Rate Parity (UIP)[1] by providing corroborating facts and some new ones for EM currencies. We do so by utilizing a propriety dataset that we believe is superior to publicly available alternatives. Second, our calculation of the excess return takes into account institutional features of the foreign exchange market. They include lags in settling spot contracts, FX (foreign exchange) swaps[2], and bid/offer spreads.

There are two classes of tests of UIP. One, sometimes called the unconditional test (so named by Geert Bekaert and Robert Hodrick (1993)), examines whether the mean excess return is significantly different from zero. The other, the conditional test, can be performed by regressing the excess return on the forward premium (which equals the interest-rate differential or what is commonly called the *carry* by foreign exchange traders). The extensive literature reports that, while it survives the unconditional test, UIP fails spectacularly on the latter test, with the carry coefficient in the excess return regression far above the theoretical value of zero and often above two. This phenomenon is known as the forward premium puzzle.[3]

[1] UIP states that the forward exchange rate is an unbiased predictor of the future spot rate at maturity. See Charles Engel (1996) for a comprehensive survey. Lustig, Roussanov, and Verdelhan (2008) contain a concise survey of recent empirical studies.

[2] An FX swap is a contract to buy spot an amount of currency at an agreed rate and simultaneously resell usually but not necessarily the same amount of currency for a later date also at an agreed forward rate.

[3] The forward premium puzzle can also be framed in the Fama (1984) regression, in which the dependent variable is the spot return rather than the excess return. The forward premium puzzle in terms of the Fama regression is that the carry coefficient is far less than the theoretical value of unity and often

Those results found in the literature are for major currencies. Our results from the unconditional test for EM currencies are very different. For the period starting in the second half of the 1990s and including the two major crises (of the 1997 East Asian currency crisis and the recent global systemic crisis culminating in the Lehman shock of September 2008), we find the mean excess return to be significantly positive for many EM currencies, with a passively-managed portfolio of EM currencies providing equity-like excess returns and high Sharpe ratios. By comparison, the excess return from major currencies is, while positive, far lower in the mean. Furthermore, volatility is *lower* for EM currencies, thanks to diversification across regions.

Our results on the conditional test for EM currencies, too, are different from those for majors. First, the forward premium puzzle is less prevalent. For each EM currency, the carry coefficient in the excess return regression is, while statistically significant, small in size, typically between 0 and 1. Second, and this is what we think is new, the return from the EM currencies as a whole is better explained by the carry for *major currencies* than by the EM currency carry. However, a portfolio-based conditional test gives a different picture. That is, for EM currencies, the excess return from an actively-managed portfolio of currencies that takes long positions only in those relatively high-yielding currencies (for which the carry is more positive than others) is substantially higher than that from the passive portfolio, with a Sharpe ratio that is well above unity.

Some of these conditional test results for EM currencies have been documented by several recent papers. Jeffrey Frankel and Jumana Poonawala (2006) confirm an earlier result in Ravi Bansal and Magnus Darlquist (2000), which, if framed in the excess return regression,

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negative. Kenneth Froot and Richard Thaler (1990) carried out a survey of 75 such studies, finding that the carry coefficient was on average -0.9.

states that the carry coefficient is (still positive but) less than unity. Robin Burnside, Martin Eichenbaum, and Sergio Rebelo (2007) show that high Sharpe ratios of the excess return can be obtained from carry-based, actively-managed portfolios of a large number of currencies. Gerben de Zwart, Thijs Markwat, Laurens Swinkels, and Dick van Dijk (2008) report that various active strategies including the carry-based strategy generate Sharpe ratios above unity for EM currencies but not for majors.

The exchange rates data used by these studies are quotes assembled by WM/Reuters and disseminated by *Datastream*.[4] Besides providing the new evidence mentioned above and incorporating spot contract lags to be explained below, our contribution relative to these studies is that we utilize a propriety dataset covering longer time periods for EM currencies. The dataset was prepared by a financial institution which was committed to providing to its clients the *investible* excess returns based on it.

Turning to the second contribution of our paper, to calculate the excess return properly, one needs to take into account the lag (two days for most currencies) between the observation date (the date the spot rate is observed, also called the trading date) and the delivery date (also called the value date). If the forward contract is for delivery on, say, the last business day of a given month, the matching spot rate that goes into the excess return calculation is the rate observed two business days prior. If the active carry-based strategy is to be feasible in practice, this date alignment issue also has an implication for identifying the date for observing the carry as a signal.

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[4] Except possibly for Bansal and Darlquist (2000), which merely indicate that the data were obtained from *Datastream*. The Burnside *et. al.* study uses the WM/Reuters data available from *Datastream*. The de Zwart *et. al.* study states that their exchange rates correspond to Reuters 7am GMT mid rate fixings.

The mean excess return utilized in the above UIP tests is calculated without bid/offer spreads because UIP does not recognize them. The mean excess return is also of great interest to real-world investors contemplating on a continued exposure to currencies, but only as far as it is net of transactions costs. For a forward contract of, say, 1 month, a number of previous academic studies assume that the investor with a multiple-period horizon opens a forward position (i.e., buys or sells the foreign currency forward) and then closes or unwinds it (i.e., converts in the spot market the foreign currency amount into the base currency) one month later and repeats this operation during the investment period. But in practice this is not how market participants maintain positions. Rather, it is much cheaper to maintain, or "roll", positions via FX swaps.[5] Our currency-by-currency calculation indicates that use of FX swaps reduces transactions costs by 80 to 95 percent. We extend this calculation to passively and actively managed currency portfolios in which the allocation of positions between currencies needs to be adjusted monthly by newly opening some positions, unwinding some others, and rolling the rest of the existing positions. The investor has to pay bid/offer spread on those rebalancing trades.

The plan of the paper is as follows. Section I describes the unconditional and conditional tests of UIP. Section II describes our data and explains the date alignment in the excess return calculation by summarizing Appendix A. Section III reports our results about the unconditional tests for individual currencies and for passive portfolios. The conditional test results, one in the form of the excess return regression and the other in terms of actively managed portfolios, are in Section IV, along with our conjecture that might explain the different results from the two

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[5] This is a point we made in an earlier version (Gilmore and Hayashi (2008)) and is one also made by Darvas (2009) which came to our attention after we finished our earlier version. The forward currency transaction we consider is different from that in Darvas (2009) in that the investor is assumed to roll the whole of the existing position in each period.

conditional tests. Our results on the effect of bid/offer spreads on the mean excess return are reported in Section V along with a summary of Appendix B, which is about how to incorporate bid/offer spreads via FX swaps for individual currencies and also for passive and active portfolios. A brief summary of conclusions and an agenda for future research are in Section VI.

## I. Tests of UIP (Uncovered Interest Rate Parity)

### A. *Notation and Statement of UIP*

By way of establishing the notation, we start with a restatement of UIP (Uncovered Interest-rate Parity). We express the exchange rates in units of the domestic currency (USD (the U.S. dollar)) per unit of the foreign currency in question.[6] So let $S_t$ be the USD price of a unit of the foreign currency in question at the end of month *t*, and $F_t$ be the 1-month forward rate for delivery in the next month. UIP can be stated as

(1) $$\text{UIP: } \mathrm{E}_t(S_{t+1}) = F_t,$$

[6] Exchange rates for most currencies against USD are usually quoted in foreign currency units per USD (e.g., 82 Japanese Yen to the U.S. dollar). Our notation, which instead refers to 1 JPY being 1/82 USD, does not follow this convention because the exposition of UIP in terms of the excess return (to be defined in a moment) is more transparent (with no need to carry Jensen's inequality terms) when the exchange rate is stated as a price in USD. See, e.g., Burnside *et. al.* (2008, Section 2) for a statement of UIP using the notation similar to ours. However, later on when we report calculations to incorporate bid/offer spreads, the formulas for calculations (to be displayed in Appendix B) will adhere to the usual convention of stating the exchange rate in foreign currency units, because bid and offer rates in practice are typically quoted in foreign currency units.

where $\mathrm{E}_t$ is the conditional expectations operator conditional on information available at time *t*. We define the *excess return* from a long position in the forward contract at time $t$, $ER_{t+1}$, as[7]

(2) $$ER_{t+1} \equiv \frac{S_{t+1} - F_t}{F_t} = \frac{S_{t+1}}{F_t} - 1 .$$

This is the return when the investor goes long on the counter currency and shorts USD. (The return is an excess return because it accrues to an investment strategy that requires zero cost.) Since $F_t$ is known at time *t*, UIP can be stated equivalently as:

(3) UIP restated: $\mathrm{E}_t(ER_{t+1}) = 0$.

The left hand side of this equation is the *(conditional) risk premium*. So UIP states that the risk premium is zero for all dates.

We define the *forward premium* to be the percentage difference between the spot and forward rates. Under CIP (covered interest rate parity), the forward premium equals what is called the *carry*, which is the interest rate differential between the two currencies (the interest rate in the foreign currency minus the domestic currency (USD) interest rate). In this paper we use the term "forward premium" and "carry" interchangeably, although *none* of our results will depend on whether CIP holds or not. Thus,

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[7] More often, researchers state UIP and the excess return in terms of logs: $\mathrm{E}_t(\log(S_{t+1})) = \log(F_t)$ and $ER_{t+1} \equiv \log(S_{t+1}) - \log(F_t)$. Because the log difference approximately equals the percentage difference (i.e., $\log(x) - \log(y) \approx \frac{x-y}{y}$), all the results to be reported in the paper are virtually identical with the log version. We chose to use the non-log version because the exact expression for the excess return that the investor receives is (2) in the text, not the log difference.

$$carry_t \equiv \frac{S_t - F_t}{F_t} = \frac{S_t}{F_t} - 1. \tag{4}$$

From the definition of the excess return and the carry, it follows that

$$1 + ER_{t+1} = \frac{S_{t+1}}{F_t} = \frac{S_{t+1}}{S_t}\frac{S_t}{F_t} \quad \text{or} \quad ER_{t+1} \approx \frac{S_{t+1} - S_t}{S_t} + carry_t\ , \tag{5}$$

That is, the excess return can be decomposed into the spot return and the carry. This expression emphasizes the point (already apparent in (2)) that the only source of uncertainty is the foreign exchange risk that the spot rate one month hence is not known.[8]

[8] The counterparty to the forward contract may default, but we believe the counterparty risk is of minor significance. If the counterparty defaults during the contract period, the investor needs to replace the forward position at the then prevailing exchange rate. Whether reconstructing the position is costly or not depends on the continuation value of the contract. The value, which of course was initially zero when the contract was traded, may be positive or negative. Suppose, for the sake of explanation, the value is positive and the position reconstruction is therefore costly. This is the case if the prevailing forward rate is less favorable to the long investor than the original rate. The current standard practice stipulated by the ISDA (International Swap and Derivatives Association) is that the defaulting party (or its estate) must compensate the investor for the loss of value. If the defaulting party had posted collateral, the investor may be able to obtain a full compensation.

During financial crises, EM currencies tend to depreciate against USD (this was indeed the case during the Lehman crisis), so for the investor who was long EM currencies against USD, the opposite is true. That is, the investor can reconstruct the position at a more favorable forward rate but owes money to the defaulting counterparty, not the other way round. In this case as well, the counterparty risk is mitigated to a large extent if the investor had posted collateral or if the bankruptcy court enforces payment (for a bankruptcy court case, see an article entitled "Lehman Bankruptcy Court Holds ISDA SWAP Counterparty in Violation of Automatic Stay/ Counterparty Seeks Modification" by Mark Ellenberg and Leslie Chervokas, originally published September 29, 2009, and available from the website of Free Library by Farlex). Therefore, regardless of the sign and magnitude of the continuation value, and besides legal fees and other administrative expenses, the counterparty risk does not seem important.

We note three points here. First, taking a position requires no cash outlays, so the excess return does not depend on the investor's access to funding. Second, the excess return equals the return from a *carry trade* only if the investor can borrow and lend at the safe interest rate, i.e., only if the carry trade does not involve credit risk.[9] Third, even when the currency is pegged to USD (so the USD spot return is zero), the excess return may not be zero because the carry may not necessarily be zero. For example, if market participants anticipate an imminent devaluation (as occurred to Argentine Peso in weeks leading up to the eventual devaluation in January 2002), the carry (and hence the excess return prior to devaluation) is positive.

B. *Tests of UIP*

The null hypothesis in the *unconditional test* of UIP is

(6) the null in the unconditional test: $\mathrm{E}(ER_{t+1}) = 0$,

which is implied by UIP by taking the unconditional expectation of both sides of (3). We will test the null hypothesis in two ways. First, we will conduct the usual *t* test for each currency. Needless to say, the statistic used in the *t* test is the sample mean of the excess return over the sample period, i.e., the cumulative excess return from continued exposure to 1-month forward

[9] In a carry trade, the investor borrows at the USD short-term interest rate, invests the borrowed amount in the foreign currency, and then converts the return and the principal into USD. The return from the carry trade is $(1+r_t^*)S_{t+1}/S_t - (1+r_t)$, where $r_t^*$ is the foreign currency interest rate from date $t$ to $t+1$ and $r_t$ is the USD interest rate. CIP states that $S_t / F_t = (1+r_t^*)/(1+r_t)$. Eliminating $S_t$ from these two equations, we obtain $(1+r_t^*)S_{t+1}/S_t - (1+r_t) = (1+r_t)(S_{t+1}/F_t - 1)$. So the carry-trade return is proportional to the excess return defined in equation (2) of the text.

contracts. The same statistic is the object of great interest for real-world long-term investors.[10] Second, to test for the risk premium for a group of currencies, we will examine the *index excess return*, defined as the excess return from a *portfolio* of currencies that is passively managed to equal weights.

The *conditional test* examines whether the excess return from $t$ to $t$+1 can be predicted by some variable whose value is known at time $t$. The variable that attracted most attention in the literature is the carry. Consider the excess return regression

$$ER_{t+1} = \alpha + \gamma \cdot carry_t + u_t \,. \tag{7}$$

Under UIP, both $\alpha$ and $\gamma$ are zero. As is well known (see, e.g., Fumio Hayashi (2000, Chapter 6)), UIP implies that those conditions under which the OLS (ordinary least squares) estimator is consistent (except the one requiring that the variables be ergodic stationary, which we assume here) are satisfied. We will also conduct a portfolio-based test of the predictive ability of the carry by examining the return from a portfolio that is actively managed based on the carry as the signal.

*C. Relation to the Fama Regression*

The more popular, and nearly equivalent, form of the conditional test in the literature is the "Fama regression" in Eugene Fama (1984):

$$\log(S_{t+1}) - \log(S_t) = \alpha + \beta \cdot (\log(F_t) - \log(S_t)) + u_t \,. \tag{8}$$

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[10] It is interesting to note that, although the null of UIP is about the pure foreign exchange risk, the mean excess return in the $t$ test involves not only the foreign exchange risk but also the interest rate risk because it depends on the sequence of the carry (the interest rate differential) as well as the spot rate.

Since under UIP the forward premium is an optimal predictor (in the sense of minimizing the mean squared error) of the actual rate of change of the spot rate, we have $\alpha = 0$ and $\beta = 1$. The well-known *forward premium puzzle* is that the OLS estimate of $\beta$ is far less than unity, often negative and more like $-1$ than 0. Since $ER_{t+1} \equiv \frac{S_{t+1} - F_t}{F_t} \approx \log(S_{t+1}) - \log(F_t)$ and $carry_t \equiv \frac{S_t - F_t}{F_t} \approx \log(S_t) - \log(F_t)$, the excess-return regression (7) can be written approximately as

(9) $$\log(S_{t+1}) - \log(F_t) \approx \alpha + \gamma \cdot (\log(S_t) - \log(F_t)) + u_t \, .$$

Subtracting $\log(S_t) - \log(F_t)$ from both sides of this equation, we obtain

(10) $$\log(S_{t+1}) - \log(S_t) \approx \alpha + (1-\gamma) \cdot (\log(F_t) - \log(S_t)) + u_t \, ,$$

which is the Fama regression. That is, the $\alpha$ in the Fama regression is approximately equal to the $\alpha$ in the excess-return regression, and

(11) $$\gamma \approx 1 - \beta \, .$$

Therefore, the forward premium puzzle in terms of the excess-return regression is that the OLS estimate of the carry coefficient $\gamma$ is far greater than zero, often above 2.

## II. The Data and the Excess Return Calculation

### A. *The Baskets of Currencies*

We obtained daily data on over-the-counter spot and forward rates against USD (the U. S. dollar) for 20 EM (emerging market) currencies and 9 major currencies. The 20 EM currencies (to be referred to as “EM20”) are listed in Table 1A, and the 9 major currencies (to be referred to as

"G9") are in Table 1B. We will also use data on three EUR (Euro) legacy currencies, DEM (Deutsche Mark), FRF (French Franc), and ITL (Italian Lira), for the pre-Euro period.

The main criteria for choosing EM currencies for our study are the following. The first is existence of sufficient historical data on spot and forward rates, reflecting what could potentially have been traded by international counterparties. The second is liquidity. The assessment of this criterion is by necessity somewhat subjective, but the above set of currencies (plus exceptions noted below) approximates, but is not identical to, those identified by the BIS Triennial Survey as having the highest daily turnover. Third, some currencies that are occasionally classed as emerging market currencies have been deliberately excluded. The most notable are the Singapore Dollar and the Hong Kong Dollar. In both cases high per capita incomes and levels of development suggest they cannot comfortably be classified as emerging market currencies. Fourth, we excluded those currencies that were sustainably pegged to a major currency over the entire sample period of from the late 1990s. Perhaps the most prominent in this category is the Saudi Arabian Riyal.

ARS (Argentine Peso) and CNY (Chinese Yuan), two of our 20 EM currencies, were pegged to USD for part of the sample period. ARS was pegged to the USD until January 4, 2002. For CNY, the authorities intervened to maintain the spot rate within a very narrow range until July 20, 2005. We will include those periods with (near) constant exchange rates in our excess return calculation because the excess return, which equals the carry (i.e., the forward premium) when the spot rate is constant (see (5)), fluctuated in anticipation of potential future moves in the spot rate.

## B. *Data Source*

There are two datasets of daily exchange rate observations that we used for EM20. The first is a dataset prepared by AIG-FP (AIG Financial Products International, Incorporated and its subsidiaries) using its own proprietary database. For each day and for each currency in the sample, the mid value of the exchange rate is recorded at the time of the day when the over-the-counter market is deemed most liquid. The series on the spot and forward rates start as early as May 1996 for some EM currencies. Where gaps or deficiencies existed, a combination of additional sources was used with the aim of preparing a dataset that represented prices that were tradable by international or offshore market participants. As a result, where significant capital controls or other restrictions exist in a particular country, rates observed in non-deliverable forward (NDF) markets have been used.[11] AIG-FP used this proprietary data to construct a family of *investible* emerging market indexes (called the AIG-EMFXI[SM] family) in a way similar to — but not identical to — our EM20 index to be explained later in Section III.B. We have taken some comfort in the knowledge that the individual currency series derived from the underlying spot and forward observations in the AIG-FP dataset correspond closely to those derived independently by JP Morgan in its short-dated local currency emerging market index (the ELMI+ index). We have not attempted to access the underlying spot and forward rate data used by JP Morgan.

The other daily dataset, called the WM/Reuters Historic Rate Data, is one compiled by WM/Reuters (The World Markets Company plc ("WM") in conjunction with Reuters), whose spot rates, covering a large number of currencies including EM20 and G9, are widely used by

[11] As at June 2008 data on eleven of the 20 EM currencies came from the NDF market which is cash settled. They are: KRW, IDR, PHP, CNY, TWD, INR, BRL, CLP, COP, ARS and RUB. International market participants actively trade RUB in both non-deliverable and deliverable markets.

fund managers, custodians and index compilers.[12] Their forward rate series start from December 31, 1996, for some currencies and later (from 2004) for most others. Offer and bid rates as well as mid rates are available.

Since the series for most EM currencies starts earlier in AIG-FP (with all the six East Asian currencies starting earlier than the East Asian currency crisis of mid 1997 to January 1998), we take the AIG-FP dataset to be the primary source. There is a need to combine the two daily datasets, though, because both datasets contain a significant number of repeated observations (with the same value recorded over consecutive weekdays for the spot rate or the forward rates or both) and because AIG-FP's sample period ends in April 19, 2010. Repeated observations occur primarily for TRY in 2002 in AIG-FP and for IDR in 2000-2007 in WM/Reuters. Since both data sources generate similar monthly returns for periods when both are available (see Appendix Table 1 of Stephen Gilmore and Fumio Hayashi (2008)), we decided to supplement AIG-FP by WM/Reuters by importing the WM/Reuters mid rates (if available) for days on which AIG-FP has no information. For more details about repeated observations and how to combine the two daily datasets, see Appendix A.1.

For G9, our data source is the G9 component of the WM/Reuters data.

### C. *Date Alignment in the Excess Return Calculation*

We define the 1-month excess return to be the return on 1-month forward contracts whose delivery date is the end (the last business day) of each month (such forward contracts are sometimes called *end/end deals*). This means that both the forward rate $F_t$ and the corresponding spot rate $S_{t+1}$ that go into the excess return formula (2) are for delivery on the last

[12] For details, see a WM/Reuters document entitled *Spot & Forward Rates Guide* available from the web.

business day of month $t$+1. Obtaining the appropritae spot and forward rates is not a straightforward task for two reasons.

First, even for spot contracts there is a lag between the observation date (the date when the contract is traded and the exchange rate is observed, also called the trading date) and the delivery date (also called the value date).[13] Date alignment, that is, identifying relevant observation dates for spot and forward contracts, requires a delivery schedule that maps observation dates to delivery dates.

To provide an example of date alignment, take JPY to be the counter currency. For delivery at the end of April 2009 (on Thursday, April 30, 2009), the 1-month forward JPY/USD rate is observed on Friday, March 27, 2009, while the spot rate is observed on Monday, April 27 (the 3-day lag to April 30 is due to April 29 being a national holiday). The excess return on end/end deals from March to April is the difference between the spot rate observed on April 27 and the forward rate observed on March 27. AppendixA.1 and A.2 explain in detail how we performed this data alignment.

Second, for correctly identified spot and forward observation dates, our daily data may have missing observations on the exchange rates. For EM20, this occurs in 88 of the 3,197 currency-months listed in Table 1A. When the relevant dates have missing exchange rate values, we turned to neighbouring dates with valid data, which means that either the spot rate or the forward rate (or both) is not for delivery on the last business day of the month. Therefore, the "excess return" in those 88 cases differs from the excess return on end/end deals by a spot return arising from the discrepancy (typically one or two weekdays and at most several days) between

[13] The lag is zero or one business day for TRY, one business day for CAD, PHP, and RUB and two business days for other currencies.

the last business day of the month and the actual delivery dates. Appendix A.3 has more details about those problem cases. There were no problem cases for G9.

## III. Unconditional Tests of UIP

### A. *Simple Statistics of the Excess Return and the Carry*

Simple statistics for monthly excess returns are reported in Table 1 along with those for the carry (i.e., the interest rate differential measured by the forward premium) for periods ending in December 2010. Panel A of the table has EM20 (the 20 emerging market currencies) ordered by the time of data availability. Panel B has G9 (the 9 majors). The following are noteworthy.

- For EM20, as indicated by its *t*-value, the mean excess return is significantly different from zero at the 5% level for nearly half the currencies. In sharp contrast, *no* G9 currency exhibits a mean excess return that is significant, even at 10%. That is, the null hypothesis (6) can be rejected for a number of EM currencies but not for majors.

- The volatility of the excess return for EM20, ranging from 1% for CNY to nearly 40% for IDR, is on average *not* much higher than that for G9.

- The average cross-currency correlation shows that the excess returns are correlated less among EM20 than among G9.

- Turning to the carry, except for TWD, it has on average been positive and generally much higher for EM20 than for G9.

- Looking across currencies, we note that the mean excess return is positively associated with the mean carry (a point we will come back to later in the paper). Volatility has no clear association with the mean excess return.

B. *The Unconditional Test on Passive Portfolios*

It is of interest to see if the risk premium is positive for EM20 as a whole. We could calculate the *t*-value for a pooled sample of the 20 currencies. However, to investors seeking exposure to emerging market currencies as an asset class, a far more interesting way to test for joint significance is to look at the return from a *portfolio* of those currencies. For this purpose, we created excess return indexes, one for EM20 and the other for majors. The index takes a long position in an equally-weighted basket of 1-month forward contracts versus USD. The trading rule used to form the portfolio is therefore *passive*. At the end of each month, the portfolio is rebalanced. To be more precise, let $Y_t$ be the index value at the end of month *t*, for either EM20 or G9. Then calculate the index values as a cumulative excess returns by the formula

(12) $$\frac{Y_{t+1} - Y_t}{Y_t} = \frac{1}{\# B(t)} \sum_{j \in B(t)} ER_{j,t+1} ,$$

where $ER_{j,t+1}$ is the USD excess return from time $t$ to $t+1$ for currency $j$, $B(t)$ is the basket of constituent currencies for which data on the excess return from the end of month *t* to *t*+1 is available, and $\# B(t)$ is the cardinality (the number of constituent currencies) of $B(t)$.

The basket $B(t)$ for EM20 can be read off from Table 1A for each month *t*. We have, for example,

*B*(June 96) = {TWD, THB, ZAR, TRY},

*B*(January 97) = {TWD, THB, ZAR, TRY, PHP, KRW, CNY, IDR},

*B*(May 97) = {TWD, THB, ZAR, TRY, PHP, KRW, CNY, IDR, PLN, CZK, CLP, MXN},

*B*(June 98) = {20 EM currencies except ILS and RUB}.

Therefore, during the East Asian currency crisis of the second half of 1997, there were twelve constituent currencies in the EM basket and as many as half of them were East Asian currencies. As a result the basket is not as diversified as for later periods and so may not be as reflective of emerging market foreign exchange as an asset class. Indeed, it would be reasonable to assume that given that the basket includes a high exposure to currencies that were directly affected by the crisis it might be a negatively biased sample.

For G9, for the pre-Euro period, we use DEM, FRF, and ITL as the legacy currencies that EUR replaced, so the "G9" actually consists of eleven currencies before the introduction of the Euro:

$B(t)$ = {AUD, CAD, JPY, NZD, NOK, SEK, CHF, GBP, DEM, FRF, ITL} for $t$ < January 1999,

$B(t)$ = {AUD, CAD, JPY, NZD, NOK, SEK, CHF, GBP, EUR} for $t \geqq$ January 1999.

Therefore, for example, the last observation of the DEM excess return used for the G9 index is from the end of December 1998 to the end of January 1999, and the first EUR excess return observation is from January to February 1999.

Figure 1 graphs the EM20 and G9 indexes normalized to 100 at June 1998. The EM20 excess return index shows a sharp drop during the East Asian crisis from November 1997 to January 1998, followed by a rebound in February and March 1998. This swing took place when the basket size is 13 to 16 currencies. The Brazilian devaluation of early 1999, the Turkish devaluation of early 2001 and the Argentine crisis of early 2002 hardly affect the performance of EM20, thanks in part to the increased basket size. The increased basket size, however, was not enough to prevent the large drop of the EM index during the global systemic crisis from July 2008 to February 2009, followed by a quick recovery. The G9 index showed almost a parallel movement during that period, indicating that there was a general rise and then fall of USD against most currencies.

Table 2 displays summary statistics of the EM20 and G9 indexes for two sample periods. Although the index for EM20 can be calculated from June 1996, the earliest starting date is taken to be January 1997, because over several months from June 1996 the index covers just four currencies (TWD, THB, ZAR, TRY) and also because it is the earliest starting date for the G9 index using WM/Reuters data. The first sample period is from January 1997 to December 2010. The second sample period, spanning 10 years from June 1998 to June 2008, excludes the two crises (of the East Asian crisis and the global systemic crisis). The following are noteworthy features of the table.

- The mean excess return is positive for both the EM20 and G9 indexes, although it is statistically significant only for EM20.
- The EM20 index exhibits *less* volatility than G9. Consequently, the Sharpe ratio is much higher for EM20. The constituents are larger in number for EM currencies, but still this finding should be surprising to many. The low volatility is due in part to the relative lack of co-movements in the individual excess returns among E20 (as shown in Table 1).[14]
- The distribution departs from normality if the two crises are included. The departure is due to the high value of kurtosis. The Jarque-Bera statistic, which is a function of skewness and kurtosis, (not shown) indicates that there is a highly significant departure from normality for the whole sample period but the significance disappears if the two crises are excluded.

## IV. Conditional Tests

[14] EM volatility is also likely to have been lower because a number of EM central banks have intervened actively to smooth currency movements against USD.

## A. *The Regression-Based Test*

Turning to the conditional UIP test, we first consider the excess return regression (7). To summarize our finding, the coefficient of the carry (the interest rate differential measured by the forward premium) is statistically significant, thus confirming the forward premium puzzle. The extent of the puzzle is less for EM20 in that the coefficient is closer to zero for EM20 than for G9. This corroborates the recent findings by Bansal and Darlquist (2000) and Frankel and Poonawala (2006).

More specifically, Table 3 displays the OLS estimates for EM20 in Panel A and for G9 in Panel B. For each currency, the sample period is the same as in Table 1.[15] Looking at Panel B first, we confirm the forward premium puzzle for G9. For most G9 currencies the estimated carry coefficient $\gamma$ in the excess return regression (7) is above 2. This implies that the $\beta$ in the Fama regression, which should be 1 under UIP, would be less than $-1$ (recall from Section I that the $\beta$ in the Fama regression (8) is about equal to $1-\gamma$). This is verified by estimated Fama regressions (not shown).

Now consider EM20 by turning to Panel A of Table 3. The carry coefficient $\gamma$ for most currencies is between 0 and 1 (correspondingly, the $\beta$ coefficient in the Fama regression is also between 0 and 1). The null hypothesis that $\gamma = 0$ in the excess return regression (or $\beta = 1$ in the Fama regression) is more strongly rejected for EM20 than for G9, because the carry coefficient is more sharply estimated.

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[15] Therefore, for ARS and CNY, for part of the sample period in which the spot rate is constant, the excess return equals the carry. Consequently, the carry coefficient is unity. This period should be included in the sample period; otherwise the OLS estimate of the carry coefficient would be biased downwards.

## B. *Conditional Test on Actively-Managed Portfolios*

A more interesting conditional test is to see whether the investor can earn a significantly higher return from a portfolio that is actively managed to exploit the predictive power of the carry. The strategy widely practiced in financial markets is the carry trade in high-yielding currencies. Since, as noted in Section I, the forward contract excess return equals the carry trade return and the carry equals the interest rate differential provided CIP (the covered interest rate parity) holds, the widely-practiced carry trade strategy is equivalent to taking long forward positions in only those currencies with a positive carry.

However, for EM20, the carry is positive for most currencies (as seen in Table 1A). We therefore consider a strategy based on the *relative*, rather than absolute, value of the carry, within the universe of available EM currencies and also within majors. That is, at the end of each month (see below for how we determine the date of the month), the investor sorts the currencies by the carry and takes equally-weighted long positions in only those currencies in the top half. We will call this strategy the *relative long-only strategy*.[16] More precisely, the index representing this strategy is defined by

$$\text{(13)} \qquad \text{relative long-only:} \quad \frac{Y_{t+1} - Y_t}{Y_t} = \frac{1}{\# B^+(t)} \sum_{j \in B^+(t)} ER_{j,t+1} \,,$$

where

$$B^+(t) = \left\{ j \in B(t) \mid carry_{jt} > \text{Median}(carry_{it}, i \in B(t)) \right\},$$

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[16] The idea of creating portfolios based on these sorts by signals has been around for decades in foreign exchange. This is a very simplified example of what rules-based traders such as CTAs do. For recent academic studies on sorted portfolios, see Gary Gorton and Geert Rouwenhorst (2006) who apply the idea to commodities and Lustig and Verdelhan (2007) who look at foreign exchange.

$B(t)$ is the basket of constituent currencies for which data on the excess return from the end of month $t$ to $t$+1 is available, and $\# B^{+}(t)$ is the cardinality (the number of constituent currencies) of $B^{+}(t)$.

We also consider, for EM20 and G9 separately, the long-short version, which we call the *relative long-short strategy*. The strategy takes long positions in the top half of the currencies (hence shorts USD) sorted by the carry and short position in the bottom half (long USD). The associated index is defined by

(14) relative long-short: $$\frac{Y_{t+1}-Y_t}{Y_t}=\frac{1}{\# B^{+}(t)+\# B^{-}(t)}\left(\sum_{j\in B^{+}(t)} ER_{j,t+1}-\sum_{j\in B^{-}(t)} ER_{j,t+1}\right),$$

where

$$B^{-}(t)=\left\{j\in B(t)\,|\,carry_{jt}<\text{Median}(carry_{it}, i\in B(t))\right\}.$$

Thus the notional (the size of the bet) is still \$1 because the absolute values of the weights add up to unity. This is a long-short index because the weights sum to zero.

If the number of constituent currencies in $B(t)$ is even, then $B^{+}(t)\cup B^{-}(t)=B(t)$ and $\# B^{+}(t)=\# B^{-}(t)=\# B(t)/2$. A simple algebra utilizing (12)-(14) shows that the difference in the excess return between the relative long-only strategy and the passive strategy numerically equals the excess return from the long-short strategy for each $t$. If the number of constituents is odd, this algebraic relation holds approximately, if not exactly. Therefore, the mean excess return of the relative long-short index should be almost equal to the difference in the mean excess return between the relative long-only index and the passive index, and we can judge from the significance of the long-short index whether the long-only index performs significantly better than the passive index.

These active strategies use the carry as a signal to pick currencies. Determining the date for observing the signal requires some care, because the date when forward contracts for end-of-month delivery are traded and observed differs across currencies and because the signal for all constituent currencies must be observed before picking currencies. To this end, we identify the earliest observation/trade date among the constituent currencies.[17] The signal is the carry observed on the *previous* business day (which for later reference will be referred to as the *signal observation date*). We do so because some foreign exchange markets are illiquid by the time Latin American currency rates are observed.[18] The signal observation date thus determined is 3 weekdays (the two day lag for spot contracts plus one day to account for global trading) to the end of the month for most currency-months. It is on average 4.0 weekdays for EM20 and 3.3 for G9.

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[17] For example, 1-month contracts for end-of-June 2008 delivery are traded (and the rate observed) on Wednesday, May 28 for most currencies and on May 29 for CAD, PHP, and RUB and May 29 or 30 for TRY depending on the time of the day. So the earliest observation date for the June 2008 delivry is May 28 for both EM20 and G9. For a very few months, the earliest observation date is closer to the middle than to the end of the month. For example, the observation/trade date for forward contracts deliverable on Wednesday, January 31, 2001 is either Tuesday, December 26, 2000 or Wednesday, December 27 for most of the EM20 currencies; Thursday, December 28 for PHP and TRY; December 22 for ILS and December 20 for IDR. So the earliest observation date is December 20 for EM20.

[18] If the spot and forward rates are not available on the signal observation date for a currency, we turn to the latest business day before that date for which the data are available for the currency. So the actual signal observation date for the month can differ across currencies. It still is the case, though, that the signal is observed for all constituent currencies before taking positions.

Ignoring this feasibility issue introduces biases in the excess return, and the size of the bias due to this seemingly minor correction is rather substantial, especially for EM20. If we use as the signal the carry on the observation day for end-of-month delivery, the mean excess returns from long-only and long-short strategies are 30 to 50 basis points higher for EM20 and 10 to 60 basis points higher for G9 depending on the sample period.

Table 4 displays simple statistics for the two active strategies for EM20 and G9 separately, for the two periods considered in Table 2. The table's main message is that the active strategies could outperform the passive strategy, especially for EM20. More specifically,

- Relative to the passive strategy, the active, carry-based long-only strategy has historically raised the excess return by 4 to 5 percentage points per annum for EM20. This improvement is highly statistically significant as indicated by the significance of the long-short strategy. For majors, the effect is much smaller in magnitude.
- Relative to the passive strategy, the active long-only strategy, whose constituent currencies are only half as numerous, raises the volatility only modestly and consequently the Sharpe ratio is higher.

Currency turnover is low due to a high degree of persistence in the ranking by the carry. For EM20, about 10% of those whose carry is relatively high for the month cease to be so in the following month. The percentage for G9 is even lower, about 5%.

### C. *Reconciling Conflicting Evidence about EM20*

Why does the carry-based, relative long-only strategy raise the mean index excess return for EM20 in spite of the low carry coefficient in the excess return regression for individual currencies? To explore the mechanism behind it, we draw a cross-section plot of the time-series mean excess return against the time-series mean carry for each currency in Figure 2, for two subsample periods. March 2004 is used to break the whole sample, because the average CPI inflation rate for EM20 counties stabilized at around 4% since 2004.[19] For both EM20 and G9, there is a fairly strong cross-section association between the excess return and the carry. The difference is that for EM20 the range for the mean carry is far more compressed in more recent years. One explanation might be a possible decline in the inflation premium in the nominal interest rates. The high persistence in the ranking noted above implies that the compression took place while preserving the ranking by the carry. If the real interest rate differential is a predictor of the subsequent excess return, this would help explain why the *relative* long-only strategy was able to pick currencies with high risk premium. The nominal interest rate differential (i.e., the carry) has a small coefficient in the excess return regression because it is a noisy measure of the real interest rate differential for EM currencies.

So far, in predicting the excess return from the currency in question, we have considered the carry of that currency only. However, as noted by, e.g., Hanno Lustig, Nick Roussanov, and Adrien Verdelhan (2008), the carry of other currencies may also help predict the excess return. Here, we address this issue of cross effects in the context of two passive long-only indexes (one for EM20, the other for G9) considered in the previous section. That is, for each index, we run a time-series regression of the index excess return (which is the cross-section mean excess return for each month) on the mean carry (the cross-section mean for the constituent currencies of the

[19] The source is IMF's *World Economic Outlook*. The inflation measure is the rate of change of the CPI for the average of the year (the WEO code PCPIPCH). The EM average inflation rate was above 10% per annum for 1996-1999, followed by about 8% for 2000-2002, and about 6% for 2003.

carry).[20] Results are shown in Table 5. Regressions #1 (for the longer sample period) and #3 (for the period excluding the two crises) show that there is no time-series correlation between the index return and the associated carry for EM20. This is consistent with the possible contamination by the inflation premium just noted. In contrast, regressions #5 and #7 show that for G9 the G9 mean carry has a strong influence on the G9 index excess return. This is a manifestation of the forward premium puzzle. Now, to examine the cross effect, in regressions #2 and #4, we regress the EM20 index excess return on the EM20 carry *and* the G9 carry. Surprisingly, the G9 carry, not the EM20 carry, emerges with higher *t* values. One possible explanation is that the excess return for individual currencies has a common global real-interest factor and the G9 carry, with less contamination by the inflation premium, is a better predictor of this factor.

## V. Incorporating Bid/Offer Spreads

In the unconditional and conditional UIP tests of the previous two sections, the mean excess return in the tests are without bid/offer spreads because UIP does not recognize them. The mean excess return is also of great interest to real-world investors contemplating on a continued exposure to currencies, but only as far as it is net of transactions costs due to bid/offer spreads. Many of the previous studies that examined mean or cumulative excess returns assume that the investor opens the foreign exchange position and then unwinds it every month, thus paying the

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[20] The index return from month $t$ to $t+1$ is given by (12) for $i =$ EM20 and G9. The mean carry for month $t$ is the average over $j \in B(t)$ of $carry_{jt}$ where $carry_{jt}$ is the carry for currency $j$ at the end of month $t$ (or more precisely, the carry on the observation day for spot contracts whose delivery date is the last business day of month $t$) and $B(t)$ is the set of constituent currencies of month $t$.

bid/offer spread on the forward outright repeatedly. The transactions cost under this trading arrangement is large: more than 100 basis points per annum for developed countries (see, e.g., Table 1 of Lustig, Roussanov, and Verdelhan (2008)) and large enough to turn the mean excess return from positive to negative for EM (emerging market) currencies (see Burnside, Eichenbaum, and Rebelo (2007)).

In practice, however, it is customary to maintain the position much more cheaply by the use of FX (foreign exchange) swaps. This section reports our results about the effect of bid/offer spreads on the mean excess return. Subsection A of this section explains how bid/offer spreads can be incorporated in the mean or cumulative excess return for individual currencies, leaving to Appendix B.1 a detailed description of sequences of trades needed to maintain (or "roll") the position. Subsection B reports results from our extension of the bid/offer calculation to passive and active portfolios. A detailed description of our methodology for the extension to portfolios is in Appendix B.2.

A. *Bid/Offer Spreads in the Currency-by-Currency Cumulative Excess Return Calculation*

Consider an investor who, instead of opening a new position and unwinding the old one every month, opens a long position via a 1-month forward outright contract in month 0, maintains or rolls the position for $n$ successive months via FX swaps, and then unwinds in month $n$. Relative to the excess return without transactions costs calculated from mid rates throughout, the investor pays the difference between the bid and mid rates (which equals half times the bid/offer spread) when opening the position in month 0, the difference between the offer and mid rates when unwinding the position in month $n$, and a monthly cost of rolling in between. The roll cost is the difference between the bid and mid of the *forward points* (the term used by foreign exchange traders for the forward premium) of FX swaps. This will be less than the difference between the bid and mid on the outright forward rate as it does not incorporate a bid/offer spread on the spot component of the transaction.

To be more succinct, *in the rest of this section*, we adopt the convention of stating the exchange rate in units of the foreign currency per base currency (USD). Let $S_t$ be the spot mid rate at the end of month $t$ (e.g., JPY 82 = 1 USD), $F_t$ the (outright) forward mid rate, and $F_t^b$ the forward bid rate. We have $F_t > F_t^b$. The forward rate applicable when the position is being rolled, denoted $\tilde{F}_t$, is given by (B1) of Appendix B.1 and reproduced here:[21]

$$\tilde{F}_t = F_t - \frac{1}{2}\left[\left(F_t^o - F_t^b\right) - \left(S_t^o - S_t^b\right)\right], \tag{15}$$

where $S_t^b$ and $S_t^o$ are bid and offer spot rates. The term $\frac{1}{2}\left[\left(F_t^o - F_t^b\right) - \left(S_t^o - S_t^b\right)\right]$ is the roll cost mentioned above. The low roll cost means that $\tilde{F}_t$ is much closer to the mid rate $F_t$ than to the bid rate $F_t^b$. The cumulative gross (i.e., 1 plus) excess return from continuous exposure to the currency between dates 0 and $n$ is

(16) Cumulative gross excess return from date 0 to $n$ $= \dfrac{F_0^b}{S_1} \times \dfrac{\tilde{F}_1}{S_2} \times \cdots \times \dfrac{\tilde{F}_{n-2}}{S_{n-1}} \times \dfrac{\tilde{F}_{n-1}}{S_n^o}$,

[21] The expression (B1) or (15) assumes FX swaps in which the amounts in the spot and forward legs of the swap transaction differ slightly by an interest rate component. Such "uneven" FX swaps has become popular in recent years. If only "even" FX swaps are allowed, the expression for the applicable forward rate, which is (B4) of Appendix B.1, is slightly more complicated. The discrepancy between (B1) and (B4) is tiny in our data, typically far smaller than 1 basis point per annum.

where $S_n^o$ is the spot offer rate at exit.[22] The applicable spot rate except when unwinding the position is the mid rate $S_t$ because FX swaps, not outright forward contracts, are used to maintain the forward position. Needless to say, the cumulative gross excess return without transactions cost is obtained by replacing $F_0^b$ by $F_0$, $\tilde{F}_t$ by $F_t$, and $S_n^o$ by $S_n$.

We define the transactions cost per month as the difference in the geometric mean of the excess return with and without bid/offer spreads.[23] As shown in Appendix B.1, it is approximately equal to

(17) Transactions cost per month

$$\approx \frac{1}{n}\left[\frac{1}{2}\left(\frac{F_0^o - F_0^b}{F_0} + \frac{S_n^o - S_n^b}{S_n}\right)\right] + \frac{n-1}{n}\left[\frac{1}{n-1}\sum_{t=1}^{n-1}\frac{1}{2}\frac{\left(F_t^o - F_t^b\right) - \left(S_t^o - S_t^b\right)}{F_t}\right].$$

The first term in (17) is the entry and exit costs. It is divided by $n$ because the investor incurs these costs only once. The second term represents the cost of rolling. Since the roll cost as a fraction of the mid forward rate, $\frac{1}{2}\frac{\left(F_t^o - F_t^b\right) - \left(S_t^o - S_t^b\right)}{F_t}$, has to be paid every month, the second term is an average over the interim months $t = 1,2,...,n-1$ of the investment period. Obviously,

[22] If the NDF (non-deliverable forward) market is used, the applicable spot rate when unwinding is not the offer spot rate but the mid rate. So for NDFs mentioned in footnote 11, the offer spot rate $S_n^o$ should be replaced by the mid rate $S_n$.

[23] We can also define the transactions cost as the difference in the arithmetic mean or as the $n$-th root of the ratio of the cumulative gross excess return without bid/offer spreads to that with bid/offer spreads less unity. All these three definitions give virtually the same transactions cost estimate in our data. See Appendix B.1 for more details.

if $n$ is sufficiently large, the spot bid/offer spreads are insignificant and the transactions cost is approximately equal to the average roll cost.

How big are those components of the transactions cost? Table 6 has the spot and forward bid/offer spread and the annualized roll cost calculated from the WM/Reuters data for a period ending in June 2008. The bid/offer spreads on spot and forward contracts have been declining slowly but steadily over recent several years, until the summer of 2008. The table shows averages only since March 2004, because the coverage of EM currencies by WM/Reuters becomes comprehensive only since then. The table shows that transactions costs are far higher for EM currencies, and within EM currencies there is a great deal of heterogeneity. Nevertheless, if we focus on averages, the annualized roll cost — excluding the entry and exit costs — was about 30 basis points per annum. For G9, it was almost negligible, about 2 to 3 basis points.

If (as most previous academic studies assume) the investor repeats the operation of opening a new position and unwinding the old one, the transactions cost is approximately equal to

$$\frac{1}{n}\sum_{t=0}^{n-1}\frac{\frac{1}{2}\left(F_t^o-F_t^b\right)}{F_t}+\frac{1}{n}\sum_{t=1}^{n}\frac{\frac{1}{2}\left(S_t^o-S_t^b\right)}{S_t}. \tag{18}$$

If the averages shown in Table 6 are to be used, the approximate annualized transaction cost equals about 160 (= 12 times (11.1+16.0)/2) basis points for EM20 and about 60 (= 12 times (4.7+5.1)/2) basis points for G9. That is, the transactions cost of a rolled-over position is only 5 to 20 percent of the cost of a corresponding new transaction, a magnitude similar to what Zsolt Darvas (2009) found for major currencies.

We hasten to add, though, that these historical transactions cost estimates should be viewed as providing only indicative orders of magnitude for the marginal cost faced by entities that have direct access to the over-the-counter interbank foreign exchange market.  In practice there are several reasons why the actual costs faced by a market participant might be different from these estimates, although we expect that on average the differences between the costs we derive from WM/Reuters data and the costs actually faced by a market participant would be relatively small.  First, the reported bid/offer spreads might not be accessible for a specific market participant.  This can occur for instance when a market participant does not have available credit lines or a dealing relationship with the bank making the quote to a broker (or WM/Reuters) — something that is likely to be more of an issue for emerging market currencies where the bank making the quote might be located in one of the EM countries.  Second, even if prices are accessible they may only be accessible in relatively small volumes — again a factor that is likely to be more relevant for EM than the major markets.  (This is likely to be less of a problem when rolling positions than with spot transactions, though.)  Third, market participants may not necessarily face the full bid/offer.  Fourth, bid/offer spreads will vary with market liquidity and the time of the day.  For instance the bid/offer spread will be wider on Latin American currencies in Asian hours or in European hours prior to the opening of the US markets. Our conversation with foreign exchange traders leads us to suspect that the roll costs calculated from the WM/Reuters data (shown in Table 6) have historically appeared too low for some currencies, e.g., IDR, COP, ARS, INR, PHP and CLP and too high for others e.g., TRY, KRW, HUF and ILS.  Finally, the underlying WM/Reuters data itself in some instances — particularly for Asian currencies — reflects local bid/offers rather than those necessarily available to international counterparties without underlying trade flows or securities to transact.

More recently, since the summer of 2008, there has been a dramatic rise in the roll cost. As the plot of daily data (from WM/Reuters) in Figure 3 shows, the average roll cost (averaged over the constituent currencies), which were more or less stable until the Lehman shock of September 16, 2008, rose sharply after the shock.[24] In December 2008, it reached levels about 5 times the pre-Lehman level, for both EM20 and G9. However, since then, the roll cost declined steadily, all the way back to the pre-Lehman level by October 2009.

### B. *Bid/Offer Spreads in Portfolio Returns*

The currency-by-currency transactions cost calculation can be extended to the passive and active index or portfolio returns of the previous two sections. To do so we need to determine, for each currency in the portfolio, the proportions of the existing position to roll and to unwind and the size of new position to open. The investor has to pay bid/offer spreads for those additional monthly trades.

Table 7 reports our calculations of the transactions cost inclusive of those rebalancing costs for the passive and active EM20 and G9 indexes, for several hypothetical investment horizons. The transactions cost is defined as the difference in the geometric mean excess portfolio return with and without bid/offer spreads. For G9, as in elsewhere, we use the WM/Reuters data, which provide bid and offer rates as well as mid rates. For EM20, we still use

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[24] The roll cost rose because the bid/offer spread on forward contracts widened by more than the spot spread during the Lehman crisis. This is documented by Michael Melvin and Mark Taylor (2009), who attribute the phenomenon to the behaviour of market makers demanding higher compensation for taking inventory risk in the face of the dramatic rise in currency volatility during the crisis. An additional explanation that has merit in our view is that there were simply fewer active counterparties in the market at that time, so end clients may simply have had fewer choices when deciding upon counterparties. As a result market makers may have faced less competition. As an aside, we would note that buyers of EM currencies and sellers of USD would have been the “right way round”. That is, during the crisis there was a scramble for USD funding. Parties rolling forward EM currency positions against USD provide that USD funding. It is therefore likely, in our view, that at the height of the crisis these parties would not have faced the full spread between the mid and bid side of the market.

the AIG-FP data (supplemented by WM/Reuters mid rates) for mid rates but obtain bid/offer spreads from the EM20 component of WM/Reuters. This requires that those EM currencies in AIG-FP be also in WM/Reuters. For this reason, the period starts from March 2004.

The upper half of Table 7 is about the passive EM20 and G9 indexes. It shows that, if the data on bid/offer spread provided by WM/Reuters are representative, the rebalancing costs are very small. Take the 48-month investment horizon from March 2004 to March 2008. The transactions cost of 31 basis points (8.03% - 7.72%) for EM20 and 4 basis points (5.09% - 5.05%) for G9 are only slightly higher than the annualized average roll costs displayed in Table 6 (of about 30 basis points for EM20 and about 3 basis points for G9). The low rebalancing costs implies that the investor pays the bid/offer spread primarily only upon entry and exit. This explains why the transactions cost quickly declines with the investment horizon: for EM20, it starts from 134 basis points for the 1-month horizon and quickly declines to 34 basis points by the time the horizon reaches 2 years. The transactions cost then rises if the investor exits after the Lehman shock of September 2008, because the bid/offer spread and hence the roll cost rose dramatically during the crisis period, as already shown in Figure 3.

With active strategies, the transactions cost should be higher because the investor has to unwind the whole position of some currencies and open new positions for others depending on the configuration of the signal. The results about active EM20 and G9 indexes are reported in the lower half of Table 7. Again, if the WM/Reuters bid/offer spreads are representative, the transactions cost is surprisingly low. For EM20, it starts at 167 basis points per annum for the 1-month horizon and declines to less than 40 basis points for investment horizons 2 years or longer. For G9, the decline is from 71 basis points to 5. That these transactions cost estimates are not much higher than those for the passive strategies shown in the upper half of the table is due to the low turnover noted earlier. If the rule underlying the active strategies required a high monthly turnover of currencies, the transactions cost would have been much higher and in the limit would be as high as that for the 1-month horizon if the strategy required the set of invested currencies to change completely from month to month.

## VI. Conclusion

The paper has four major findings about forward currency contracts. First, transactions costs due to bid/offer spreads are far lower than previously supposed in the academic literature. Second, USD investors have historically earned a positive risk premium by taking long positions in EM (emerging market) currencies and thus shorting USD, despite short-term losses during the two major financial crises. Third, an active trading strategy of picking currencies with relatively high carry substantially raises the portfolio return on EM currencies. Fourth, the carry of major currencies rather than that of EM currencies is a better predictor of the EM currency excess return.

Theoretically explaining the last three findings is left for future research. The paper is silent on why a substantial positive risk premium exists for EM currencies. Historically, USD tended to appreciate against almost all other currencies during financial crises. That the mean excess return is positive for major currencies as well as for EM currencies can be interpreted as a reward for taking short positions in USD during crises. For some reason, the reward is higher when the short position is taken against EM currencies. We offered a conjecture that might explain why the carry-based active strategy works for EM currencies despite the weakness of the carry in predicting the excess return. It remains to be seen what sort of a dynamic asset pricing theory is capable of supporting the conjecture.

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## Table 1: Summary Statistics (Sample ending December 2010)

Panel A: EM20

| Currency | Start Date | #Obs | Excess Return $\equiv (S_{t+1} - F_t)/F_t$ Mean (% p.a.) | Annualized Volatility | $t$-value for Mean | average correlation | Carry $\equiv (S_t - F_t)/F_t$ Mean (% p.a.) |
|---|---|---|---|---|---|---|---|
| TWD (Taiwan Dollar) | Jun-96 | 174 | -1.1% | 5.5% | -0.74 | 0.33 | -0.8% |
| THB (Thai Baht) | Jun-96 | 174 | 2.1% | 13.5% | 0.60 | 0.26 | 2.5% |
| ZAR (South African Rand) | Jun-96 | 174 | 6.1% | 16.6% | 1.39 | 0.26 | 7.7% |
| TRY (Turkish Lira) | Jun-96 | 174 | 17.5%**** | 17.0% | 3.92 | 0.21 | 37.1% |
| PHP (Philippine Peso) | Oct-96 | 170 | 2.0% | 9.6% | 0.78 | 0.26 | 5.2% |
| KRW (Korean Won) | Dec-96 | 168 | 2.5% | 15.5% | 0.60 | 0.36 | 3.5% |
| CNY (Chinese Yuan) | Dec-96 | 168 | 1.1%*** | 1.2% | 3.33 | 0.04 | -0.5% |
| IDR (Indonesian Rupiah) | Jan-97 | 167 | 9.3% | 37.1% | 0.93 | 0.22 | 11.3% |
| PLN (Polish Zloty) | Feb-97 | 166 | 7.6%** | 13.7% | 2.06 | 0.39 | 6.6% |
| CZK (Czech Koruna) | Mar-97 | 165 | 5.4% | 13.4% | 1.49 | 0.35 | 1.5% |
| CLP (Chilean Peso) | Mar-97 | 165 | 1.9% | 11.5% | 0.62 | 0.29 | 2.2% |
| MXN (Mexican Peso) | Mar-97 | 165 | 5.7%** | 9.7% | 2.18 | 0.28 | 8.5% |
| SKK (Slovak Koruna) | Jun-97 | 162 | 7.4%** | 11.5% | 2.37 | 0.36 | 4.0% |
| HUF (Hungarian Forint) | Dec-97 | 156 | 7.1%* | 13.7% | 1.88 | 0.41 | 6.5% |
| COP (Colombian Peso) | Jan-98 | 155 | 4.2% | 12.1% | 1.24 | 0.26 | 6.7% |
| ARS (Argentine Peso) | Jan-98 | 155 | 12.6%** | 14.8% | 3.07 | 0.05 | 24.0% |
| INR (Indian Rupee) | Mar-98 | 153 | 3.3%* | 6.2% | 1.89 | 0.32 | 4.1% |
| BRL (Brazilian Real) | Jun-98 | 150 | 10.2%* | 19.2% | 1.89 | 0.22 | 11.3% |
| ILS (Israeli Shekel) | Oct-00 | 122 | 3.6% | 8.7% | 1.33 | 0.30 | 1.8% |
| RUB (Russian Ruble) | Jun-01 | 114 | 4.9%** | 7.6% | 2.00 | 0.36 | 5.2% |

Panel B: G9

| Currency | Start Date | #Obs | Excess Return $\equiv (S_{t+1} - F_t)/F_t$ | | | | Carry $\equiv (S_t - F_t)/F_t$ |
|---|---|---|---|---|---|---|---|
| | | | Mean (% p.a.) | Annualized Volatility | *t*-value for Mean | average correlation | Mean (% p.a.) |
| AUD (Australian Dollar) | Jan-97 | 167 | 4.7% | 13.2% | 1.32 | 0.58 | 1.8% |
| CAD (Canadian Dollar) | Jan-97 | 167 | 2.4% | 8.8% | 1.02 | 0.40 | -0.1% |
| JPY (Japanese Yen) | Jan-97 | 167 | 0.1% | 10.9% | 0.05 | 0.19 | -3.3% |
| NZD (NZ Dollar) | Jan-97 | 167 | 4.2% | 13.2% | 1.20 | 0.55 | 2.6% |
| NOK (Norwegian Krona) | Jan-97 | 167 | 2.4% | 11.8% | 0.75 | 0.59 | 1.0% |
| SEK (Swedish Krona) | Jan-97 | 167 | 0.8% | 11.9% | 0.24 | 0.62 | -0.4% |
| CHF (Swiss Franc) | Jan-97 | 167 | 1.3% | 11.2% | 0.45 | 0.54 | -2.2% |
| GBP (British Pound) | Jan-97 | 167 | 1.1% | 8.9% | 0.48 | 0.47 | 1.1% |
| EUR (Euro) | Jan-99 | 143 | 1.4% | 10.9% | 0.43 | 0.64 | -0.3% |

*Notes:* Monthly data. The base currency is USD. The sample ends in December 2010 for all currencies. $ER_{t+1}$ = excess return $\equiv (S_{t+1} - F_t)/F_t$, $carry_t \equiv (S_t - F_t)/F_t$, where $S_t$ and $F_t$ are spot and 1-month forward rates, stated in USD per unit of foreign currency, at the end of month *t* (or more precisely, on the observation day whose delivery date for spot contracts is the last business day of month *t*). The excess return and the carry are at annual rates, with monthly values multiplied by 12. The mean excess return is the average of $ER_{t+1}$ ($t = t_1, t_1$+1,..., $t_2$-1), or equivalently, the average of $ER_t$ ($t = t_1$+1 $t_1$+1,..., $t_2$), where $t_1$ is the start date and $t_2$ is December 2010. So, for example for TWD, the first observation of the excess return is from June to July 96 (so $t_1$ is June 96) and the last observation is from November to December 2010. The mean carry is the average of $carry_t$ ($t = t_1, t_1$+1,..., $t_2$-1). Therefore, $ER_{t+1}$ is paired with $carry_t$. The significance of the mean excess return is indicated by stars with * = significant at 10%, ** = 5%, *** = 1%, **** = 0.1%. Annualized volatility of the excess return is defined as the standard deviation of monthly excess returns at annual rates divided by the square root of 12. “average correlation” is the average over currencies of the time-series correlation coefficients in the monthly excess return with the other currencies.

**Table 2: Index Returns**

| Index | Period | Simple Statistics of Index Excess Return | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Mean (% p.a.) | Annualized Volatility | Sharpe Ratio | *t*-value for Mean | Skewness | Kurtosis | rho(1) |
| EM20 | Jan-97 to Dec-10 (167 observations) | 5.1%** | 7.6% | 0.68 | 2.52 | -1.03 | 8.67 | 0.16** |
| | Jun-98 to Jun-08 (120 observations) | 7.8%**** | 5.1% | 1.53 | 4.83 | 0.30 | 3.51 | 0.14 |
| G9 | Jan-97 to Dec-10 (167 observations) | 2.0% | 8.4% | 0.24 | 0.90 | -0.15 | 5.05 | 0.10 |
| | Jun-98 to Jun-08 (120 observations) | 4.0%* | 7.5% | 0.53 | 1.68 | 0.46 | 2.77 | 0.09 |

*Notes:* Monthly data. The base currency is USD. The index is equally-weighted and is defined by (12). The index return is stated at an annual rate, with monthly values multiplied by 12. "rho(1)" is the sample first-order autocorrelation coefficient. Its significance is indicated by stars with * = significant at 10%, ** = 5%, *** = 1%, **** = 0.1%. The Sharpe ratio is the ratio of the mean annualized excess return to annualized volatility. The constituents of "G9" before January 1999 (when the Euro started to trade) are (AUD, CAD, JPY, NZD, SEK, NOK, CHF, GBP, DEM, FRF, ITL). The legacies (DEM, FRF, ITL) are replaced by EUR when the Euro is introduced.

**Table 3: Excess-Return Regression:** $ER_{t+1} = \alpha + \gamma \cdot carry_t + u_t$

Panel A: EM20

| Currency | #Obs | Intercept (% p.a.) | Std. Error (% p.a.) | *t*-value for $\alpha$ | Carry coefficient | Std. Error | *t*-value for $\gamma$=0 | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| TWD (Taiwan Dollar) | 174 | -0.9% | 1.5% | -0.59 | 0.24 | 0.47 | 0.50 | 0.00 |
| THB (Thai Baht) | 174 | 1.2% | 4.0% | 0.29 | 0.39 | 0.79 | 0.50 | 0.00 |
| ZAR (South African Rand) | 174 | -13.6% | 10.7% | -1.27 | 2.57** | 1.28 | 2.01 | 0.02 |
| TRY (Turkish Lira) | 174 | 6.4% | 7.3% | 0.87 | 0.30* | 0.16 | 1.91 | 0.02 |
| PHP (Philippine Peso) | 170 | 4.8% | 4.3% | 1.12 | -0.54 | 0.67 | -0.81 | 0.00 |
| KRW (Korean Won) | 168 | 5.9% | 4.3% | 1.38 | -0.99** | 0.40 | -2.49 | 0.04 |
| CNY (Chinese Yuan) | 168 | 1.3%**** | 0.3% | 4.60 | 0.50**** | 0.08 | 6.40 | 0.20 |
| IDR (Indonesian Rupiah) | 167 | -31.7%** | 13.2% | -2.39 | 3.64**** | 0.82 | 4.41 | 0.11 |
| PLN (Polish Zloty) | 166 | 5.3% | 5.4% | 0.97 | 0.35 | 0.61 | 0.58 | 0.00 |
| CZK (Czech Koruna) | 165 | 4.3% | 3.8% | 1.14 | 0.70 | 0.79 | 0.89 | 0.00 |
| CLP (Chilean Peso) | 165 | 2.6% | 3.7% | 0.69 | -0.31 | 0.96 | -0.32 | 0.00 |
| MXN (Mexican Peso) | 165 | -4.1% | 4.3% | -0.97 | 1.16** | 0.40 | 2.89 | 0.05 |
| SKK (Slovak Koruna) | 162 | 5.6% | 3.7% | 1.52 | 0.44 | 0.51 | 0.87 | 0.00 |
| HUF (Hungarian Forint) | 156 | -1.9% | 8.4% | -0.23 | 1.38 | 1.14 | 1.21 | 0.01 |
| COP (Colombian Peso) | 155 | 3.5% | 4.9% | 0.71 | 0.10 | 0.52 | 0.20 | 0.00 |
| ARS (Argentine Peso) | 155 | 11.0%** | 4.4% | 2.53 | 0.07 | 0.06 | 1.10 | 0.01 |
| INR (Indian Rupee) | 153 | -2.1% | 2.1% | -1.01 | 1.30**** | 0.31 | 4.25 | 0.11 |
| BRL (Brazilian Real) | 150 | 4.3% | 9.6% | 0.45 | 0.52 | 0.70 | 0.75 | 0.00 |
| ILS (Israeli Shekel) | 122 | 3.0% | 3.5% | 0.86 | 0.36 | 1.15 | 0.31 | 0.00 |
| RUB (Russian Ruble) | 114 | 8.3%** | 2.8% | 2.93 | -0.65** | 0.29 | -2.29 | 0.04 |

Panel B: G9

| Currency | #Obs | Intercept (% p.a.) | Std. Error (% p.a.) | $t$-value for $\alpha$ | Carry coefficient | Std. Error | $t$-value for $\gamma$=0 | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| AUD (Australian Dollar) | 167 | -3.1% | 5.0% | -0.63 | 4.30** | 1.94 | 2.21 | 0.03 |
| CAD (Canadian Dollar) | 167 | 3.0% | 2.4% | 1.27 | 4.40* | 2.33 | 1.89 | 0.02 |
| JPY (Japanese Yen) | 167 | 6.7% | 5.6% | 1.19 | 2.01 | 1.48 | 1.36 | 0.01 |
| NZD (NZ Dollar) | 167 | 0.1% | 6.3% | 0.02 | 1.56 | 2.00 | 0.78 | 0.00 |
| NOK (Norwegian Krona) | 167 | -0.2% | 3.4% | -0.06 | 2.62* | 1.38 | 1.90 | 0.02 |
| SEK (Swedish Krona) | 167 | 1.8% | 3.2% | 0.57 | 2.85* | 1.66 | 1.71 | 0.02 |
| CHF (Swiss Franc) | 167 | 8.9%* | 5.2% | 1.73 | 3.50* | 1.94 | 1.80 | 0.02 |
| GBP (British Pound) | 167 | -0.4% | 3.3% | -0.11 | 1.37 | 2.06 | 0.66 | 0.00 |
| EUR (Euro) | 143 | 2.8% | 3.2% | 0.87 | 4.27** | 2.16 | 1.98 | 0.03 |

*Notes:* The base currency is USD. Estimation by OLS on monthly data. The sample period is the same as in Table 1 for each currency. For the intercept and the carry coefficient, * = significant at 10%, ** = 5%, *** = 1%, **** = 0.1%. Recall: $ER_{t+1}$ = excess return ≡ $(S_{t+1} - F_t)/F_t$, $\text{carry}_t \equiv (S_t - F_t)/F_t$, where $S_t$ and $F_t$ are spot and 1-month forward rates, stated in USD per unit of foreign currency, at the end of month $t$ (or more precisely, on the observation day whose delivery date for spot contracts is the last business day of month $t$). The excess return and the carry are at annual rates, with monthly values multiplied by 12.

**Table 4: Conditional Tests on Actively Managed Portfolios based on Carry**

| Constituent Currencies | Strategy | Period | Simple Statistics of Excess Return from the Strategy | | | | |
|---|---|---|---|---|---|---|---|
| | | | Mean (% p.a.) | Annualized Volatility | Sharpe Ratio | *t*-value for Mean | rho(1) |
| EM20 | relative, long-only (defined by (13)) | Jan-97 to Dec-10 | 9.7%**** | 9.1% | 1.07 | 3.99 | 0.18** |
| | | Jun-98 to Jun-08 | 12.4%**** | 6.7% | 1.84 | 5.80 | 0.07 |
| | relative, long-short (defined by (14)) | Jan-97 to Dec-10 | 4.4%**** | 3.1% | 1.40 | 5.21 | 0.01 |
| | | Jun-98 to Jun-08 | 4.5%**** | 2.6% | 1.73 | 5.48 | -0.05 |
| G9 | relative, long-only (defined by (13)) | Jan-97 to Dec-10 | 3.1% | 10.0% | 0.31 | 1.16 | 0.08 |
| | | Jun-98 to Jun-08 | 6.0%** | 8.5% | 0.70 | 2.23 | 0.01 |
| | relative, long-short (defined by (14)) | Jan-97 to Dec-10 | 1.5% | 3.4% | 0.44 | 1.62 | -0.02 |
| | | Jun-98 to Jun-08 | 2.4%** | 3.1% | 0.77 | 2.43 | -0.16* |

*Notes:* The base currency is USD. The two strategies, "relative, long-only" and "relative, long-short", are based on the ranking of currencies by the carry at the end of each month (more precisely, on the signal observation day defined in Section IV.B). The "relative, long-only" strategy, defined by (13) of the text, goes long in those currencies in the top half of the ranking and no position in the rest of the currencies. The "relative, long-short" strategy, defined by (14), goes long on those currencies in the top half of the ranking and shorts the rest of the currencies. "rho(1)" is the sample first-order autocorrelation coefficient. Its significance is indicated by stars with * = significant at 10%, ** = 5%, *** = 1%, **** = 0.1%. See Notes to Table 2 for how the statistics shown here are calculated.

**Table 5: Time-Series Regression of Index Returns on Average Carry**

| Regression No. | Index | Period | Mean Excess Return (% p.a.) | Constant (% p.a.) [*t*-value] | Coefficient of E20 Carry [*t*-value] | Coefficient of G9 Carry [*t*-value] | $R^2$ |
|---|---|---|---|---|---|---|---|
| #1 | EM20 | Jan-97 to Dec-10 | 5.1% | 6.2% [*t* = 1.93] | -0.14 [*t* = -0.43] | | 0.00 |
| #2 | | | | 6.1% [*t* = 1.90] | -0.13 [*t* = -0.40] | 2.16 [*t* = 1.47] | 0.01 |
| #3 | | Jun-98 to Jun-08 | 7.8% | 5.4% [*t* = 2.20] | 0.33 [*t* = 1.27] | | 0.01 |
| #4 | | | | 6.2% [*t* = 2.51] | 0.23 [*t* = 0.91] | 2.17 [*t* = 1.92] | 0.04 |
| #5 | G9 | Jan-97 to Dec-10 | 2.0% | 2.0% [*t* = 0.90] | | 3.68 [*t* = 2.28] | 0.03 |
| #6 | | | | 2.8% [*t* = 0.79] | -0.10 [*t* = -0.29] | 3.67 [*t* = 2.27] | 0.03 |
| #7 | | Jun-98 to Jun-08 | 4.0% | 4.2% [*t* = 1.84] | | 4.52 [*t* = 2.84] | 0.06 |
| #8 | | | | 3.9% [*t* = 1.10] | 0.04 [*t* = 0.11] | 4.48 [*t* = 2.76] | 0.06 |

*Notes:* The base currency is USD. Estimation by OLS on monthly data. The indexes are the passive long-only index defined by (12).

**Table 6: Bid/offer Spreads and Roll Costs in Basis Points, March 2004 – June 2008**

| EM20 | | | | G9 | | | |
|---|---|---|---|---|---|---|---|
| | Spot | 1-month Outright Forward | | | Spot | 1-month Outright Forward | |
| Currency | Bid/offer Spread as Fraction of Mid | Bid/offer Spread as Fraction of Mid | Annualized Roll Cost | Currency | Bid/offer Spread as Fraction of Mid | Bid/offer Spread as Fraction of Mid | Annualized Roll Cost |
| TWD | 11.9 | 16.5 | 28.0 | AUD | 5.5 | 5.8 | 2.3 |
| THB | 10.3 | 15.7 | 32.4 | CAD | 4.5 | 4.9 | 2.6 |
| ZAR | 15.4 | 16.6 | 7.5 | JPY | 2.7 | 3.0 | 1.3 |
| TRY | 30.5 | 37.2 | 42.2 | NZD | 7.6 | 8.4 | 4.9 |
| PHP | 14.8 | 20.5 | 34.7 | NOK | 7.1 | 7.8 | 3.9 |
| KRW | 5.7 | 16.2 | 63.2 | SEK | 5.4 | 6.0 | 3.5 |
| CNY | 0.0 | 4.7 | 28.1 | CHF | 5.0 | 5.4 | 2.3 |
| IDR | 10.0 | 14.6 | 27.9 | GBP | 2.3 | 2.5 | 1.1 |
| PLN | 13.2 | 13.8 | 3.7 | EUR | 2.2 | 2.3 | 0.8 |
| CZK | 12.8 | 13.6 | 4.6 | | | | |
| CLP | 6.8 | 9.1 | 13.7 | | | | |
| MXN | 4.7 | 5.5 | 4.5 | | | | |
| SKK | 14.9 | 17.6 | 16.5 | | | | |
| HUF | 13.8 | 16.6 | 16.7 | | | | |
| COP | 8.6 | 20.1 | 69.5 | | | | |
| ARS | 9.3 | 21.7 | 74.4 | | | | |
| INR | 7.6 | 10.2 | 15.6 | | | | |
| BRL | 10.3 | 19.3 | 54.3 | | | | |
| ILS | 18.0 | 21.1 | 19.2 | | | | |
| RUB | 2.8 | 9.8 | 42.2 | | | | |
| Average over Currencies | 11.1 | 16.0 | 29.9 | Average over Currencies | 4.7 | 5.1 | 2.5 |

*Notes:* In basis points. The base currency is USD. The source is WM/Reuters. Averages of end-of-month values (or more precisely, averages of the rates for delivery on the last business day of the month). The sample period is March 2004-June 2008 (except for IDR whose sample period is from June 2007). The roll cost equals, as defined in Section V, 0.5 times the difference between the forward bid/offer spread and the spot bid/offer spread, expressed as fraction of the mid forward rate, multiplied by 12. The spot bid/offer spread for CNY is zero because for CNY only a single rate is quoted.

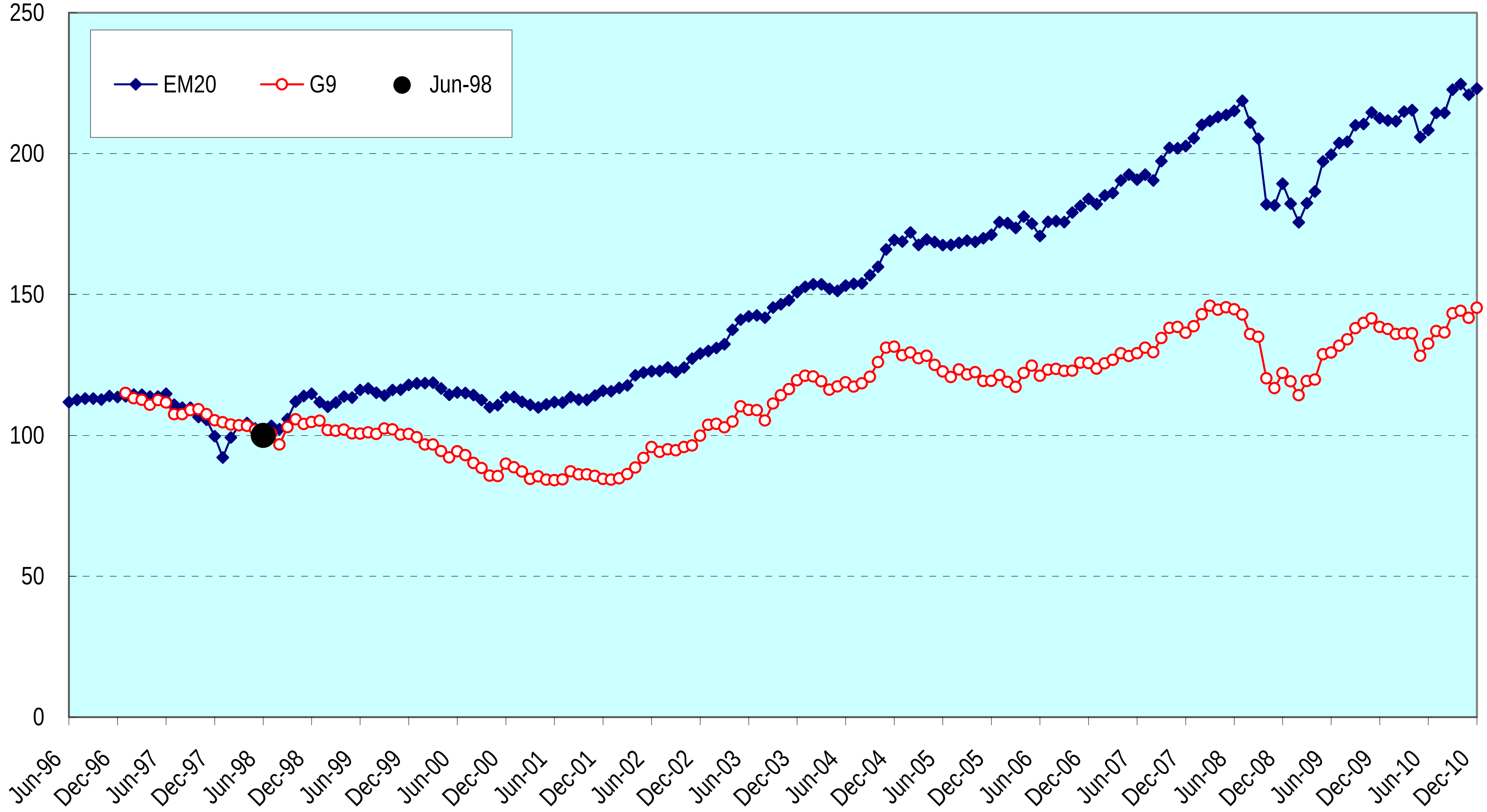
**Table 7: Transactions Costs in Portfolio Returns**

Geometric Mean Excess Returns Per Annum. Calculation assumes the investor opens position in March 2004

| Index | Bid/offer Spreads Incorporated? | Investment Horizon in Months | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 month til Apr-04 | 3 months til Jun-04 | 12 months til Mar-05 | 24 months til Mar-06 | 48 months til Mar-08 | 60 months til Mar-09 | 81 months til Dec-2010 |
| Passive on EM20 (defined by (12)) | No | -12.84% | -1.19% | 8.75% | 6.14% | 8.03% | 3.44% | 5.54% |
| | Yes | -14.16% | -1.85% | 8.35% | 5.80% | 7.72% | 3.03% | 5.11% |
| | Difference in Basis Points p.a. | 134 | 66 | 40 | 34 | 31 | 41 | 42 |
| Passive on G9 (defined by (12)) | No | -29.71% | -1.07% | 6.63% | -0.84% | 5.09% | 0.01% | 2.94% |
| | Yes | -30.22% | -1.26% | 6.55% | -0.89% | 5.05% | -0.04% | 2.89% |
| | Difference in Basis Points p.a. | 52 | 20 | 7 | 5 | 4 | 5 | 5 |
| Long-only on EM20 (defined by (13)) | No | -21.29% | 0.74% | 11.31% | 9.52% | 10.00% | 5.53% | 8.42% |
| | Yes | -22.92% | -0.04% | 10.85% | 9.15% | 9.65% | 5.07% | 7.98% |
| | Difference in Basis Points p.a. | 167 | 78 | 45 | 37 | 35 | 46 | 44 |
| Long-only on G9 (defined by (13)) | No | -29.72% | -2.45% | 8.59% | 1.40% | 7.06% | -0.07% | 3.40% |
| | Yes | -30.41% | -2.72% | 8.50% | 1.34% | 7.02% | -0.12% | 3.34% |
| | Difference in Basis Points p.a. | 71 | 27 | 9 | 5 | 4 | 6 | 6 |

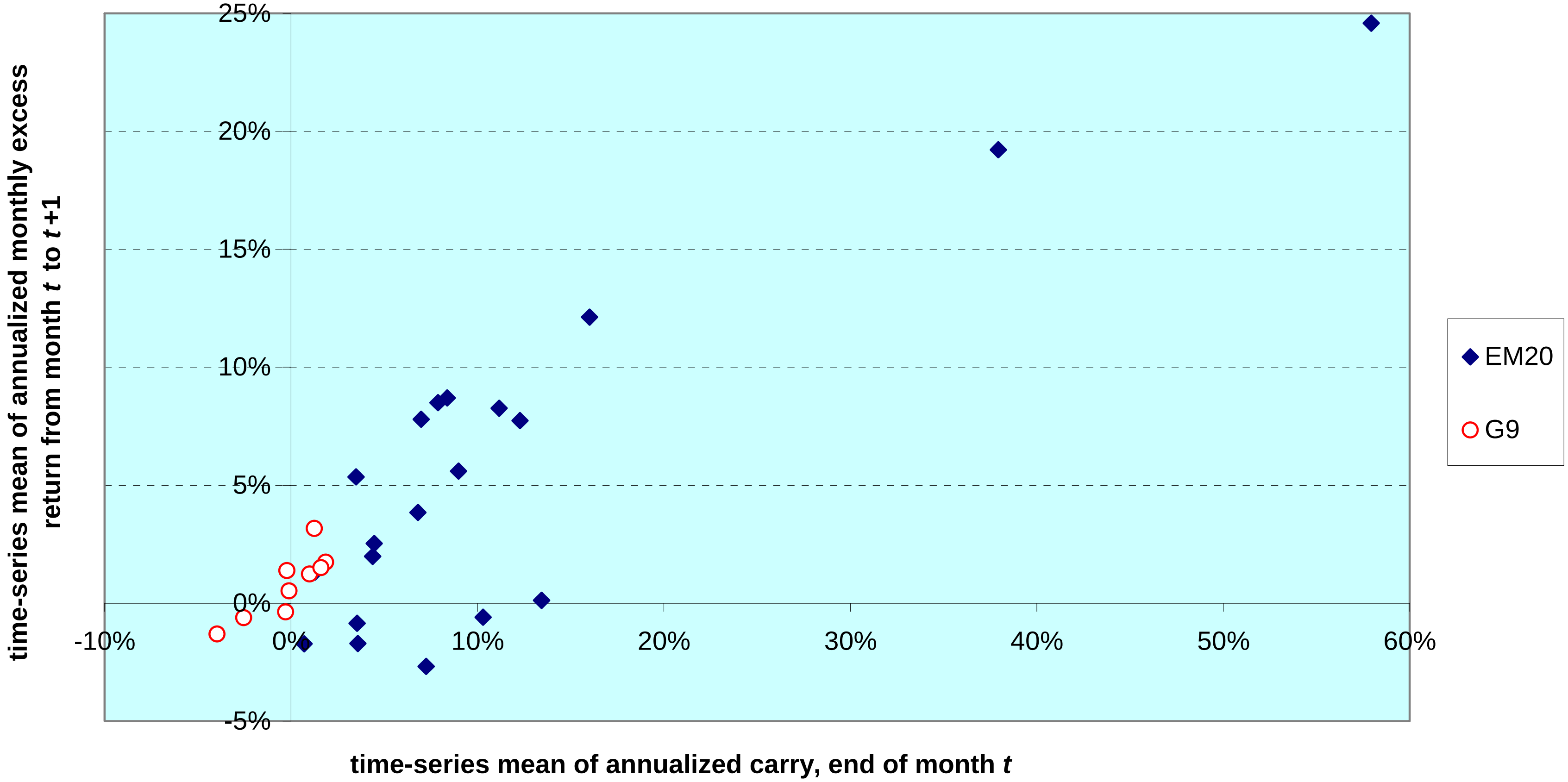
*Notes:* Monthly data. The returns are geometric means stated in percents per annum. The base currency is USD. Monthly data on bid/offer spreads (whose averages are reported in Table 6) are from WM/Reuters for both EM20 and G9. For IDR, WM/Reuters does not provide data before June 2007, so we assume the bid/offer spreads as ratios to the mid before June 2007 are the same as those in June 2007. There are 11 currency months (all coming from G9) in which the forward bid/offer spread was smaller than the spot spread. We raised the forward spread to equal to the spot spread for those currency months. We require the spot and forward bid/offer spread as a fraction of mid to be at least 2 basis points for EM20 and 1 basis point for G9 (we do so to facilitate the linear programming function of Matlab to locate the relevant corner).

Figure 1: Cumulative USD Excess Returns, EM 20 and G9, June 1996 - December 2010
June 1998 value is set to100



## Figure 2A: Cross-Section Plot of Mean Excess Return against Mean Carry

**Averages for January 1997 - March 2004**



## Figure 2B: Cross-Section Plot of Mean Excess Return against Mean Carry

### Averages for March 2004 - December 2010

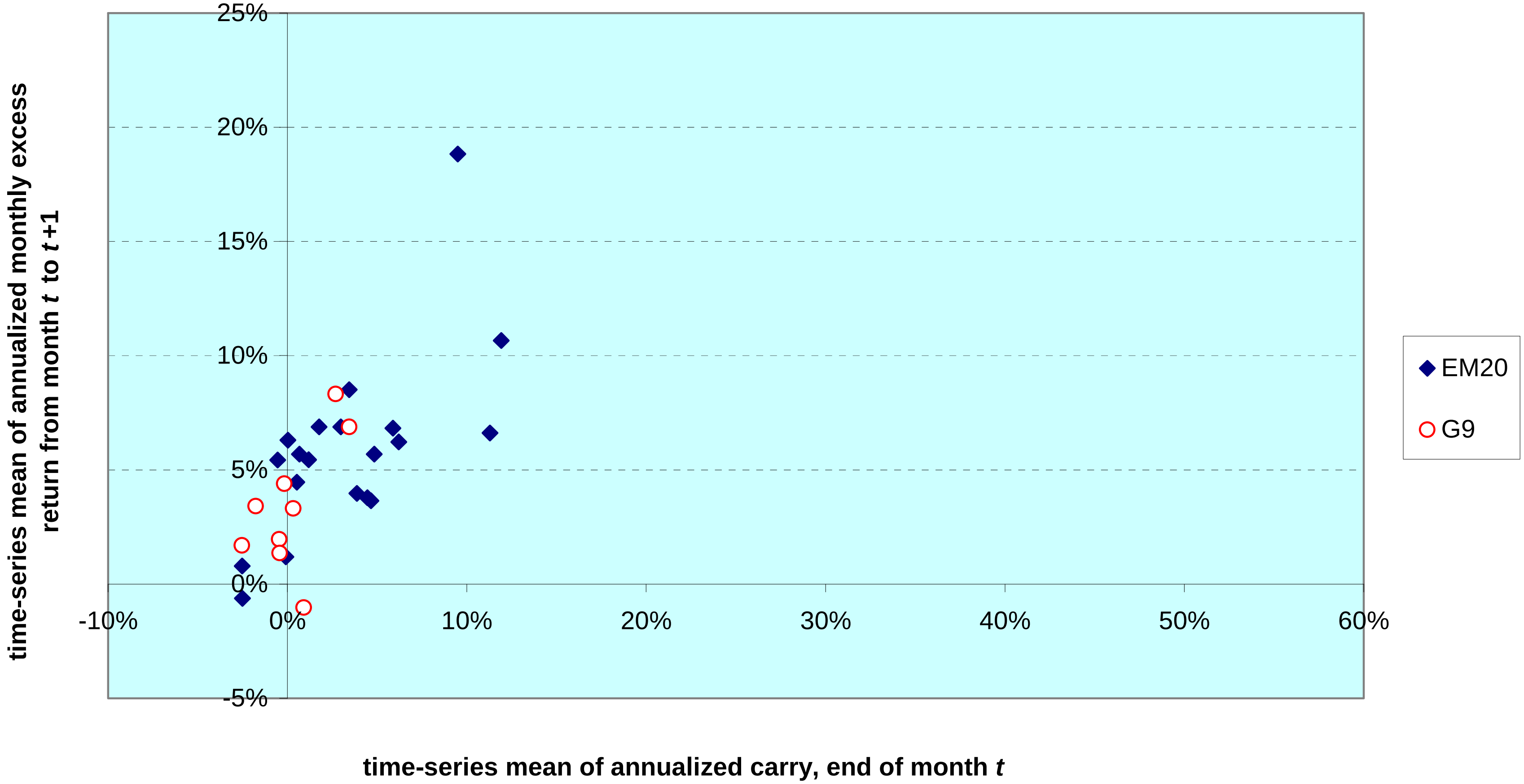
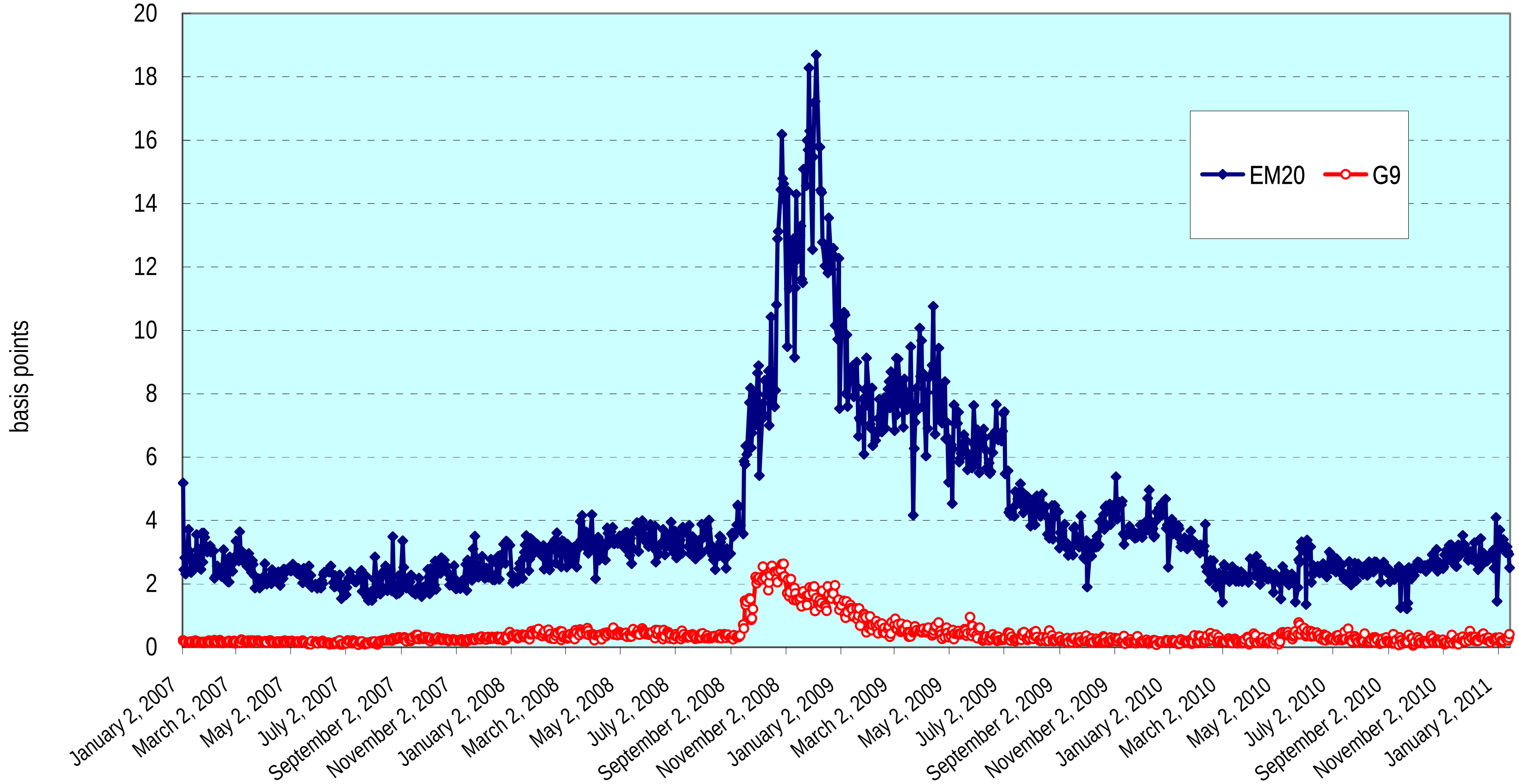


Figure 3: Roll Cost in Basis Points on 1-Month Forward Contracts
Daily data, January 2, 2007 - January 14, 2011 (Source: WM-Reuters)



## Appendixes to "Emerging Market Currency Excess Returns" by Stephen Gilmore and Fumio Hayashi, February 2011 version

## Appendix A: Documentation of the Monthly File

This appendix describes how we created the monthly file, on which all the results of the text (except for Figure 3, which is about daily bid/offer spreads) are based, from daily observations on spot and forward rates.

### A.1. Daily Files

Our procedure for creating the monthly file utilizes two files of daily observations. One, to be referred to as the Delivery Date File, was provided to us by AIG-FP (AIG Financial Products International, Incorporated). It gives the delivery dates of spot and forward contracts against USD for all weekdays between January 1980 and December 2011 for a large number of currencies including EM20 (the 20 emerging market currencies) and G9 (the 9 major currencies) listed in Table 1 and legacy currencies DEM, FRF, ITL. We write $DEL_{jt}$ for the delivery date of a $j$-month forward contract and $DEL_{0t}$ for that of a spot contract, traded on observation date $t$. This $DEL_{0t}$ will be referred to as the *spot delivery date*. We also write $OBS_{jt}$ for the observation date whose spot delivery date coincides with $DEL_{jt}$.

To provide an example, here is an extract of the Delivery Date File for JPY:

| $t$ | $DEL_{0t}$ | $DEL_{1t}$ | $DEL_{2t}$ | $DEL_{3t}$ |
|---|---|---|---|---|
| Wed, March 25, 2009 | Friday, March 27, 2009 | Monday, April 27, 2009 | Wed, May 27, 2009 | Monday, June 29, 2009 |
| Thursday, March 26, 2009 | Monday, March 30, 2009 | Thursday, April 30, 2009 | Friday, May 29, 2009 | Tuesday, June 30, 2009 |
| Friday, March 27, 2009 | Tuesday, March 31, 2009 | Thursday, April 30, 2009 | Friday, May 29, 2009 | Tuesday, June 30, 2009 |
| Monday, March 30, 2009 | Wed, April 01, 2009 | Friday, May 01, 2009 | Monday, June 01, 2009 | Wed, July 01, 2009 |
| Tuesday, March 31, 2009 | Thursday, April 02, 2009 | Thursday, May 07, 2009 | Tuesday, June 02, 2009 | Thursday, July 02, 2009 |
| ... | ... | ... | ... | ... |
| Friday, April 24, 2009 | Tuesday, April 28, 2009 | Thursday, May 28, 2009 | Monday, June 29, 2009 | Tuesday, July 28, 2009 |
| Monday, April 27, 2009 | Thursday, April 30, 2009 | Friday, May 29, 2009 | Tuesday, June 30, 2009 | Friday, July 31, 2009 |
| Tuesday, April 28, 2009 | Friday, May 01, 2009 | Monday, June 01, 2009 | Wed, July 01, 2009 | Monday, August 03, 2009 |
| Wed, April 29, 2009 | Friday, May 01, 2009 | Monday, June 01, 2009 | Wed, July 01, 2009 | Monday, August 03, 2009 |
| Thursday, April 30, 2009 | Thursday, May 07, 2009 | Monday, June 08, 2009 | Tuesday, July 07, 2009 | Friday, August 07, 2009 |

For example, for $t$ = Thursday, March 26, 2009 in the above delivery date schedule, we have: $DEL_{1t}$ = Thursday, April 30, 2009 and $OBS_{1t}$ = Monday, April 27, 2009. It is possible that multiple days qualify as $OBS_{jt}$: an observation date of $t =$ Monday, March 30, 2009 has $DEL_{1t}$ = Friday, May 1, 2009, and two observation dates, April 28 and April 29, share the same spot delivery date of May 1. As this JPY example illustrates, it appears that national holidays of the country of the counter currency are not a delivery day (Wednesday, April 29, 2009 is a Japanese national holiday).

The other file is what we call the Price File, which has daily observations on the over-the-counter spot and forward rates against USD for EM20 and G9. There are two data sources for daily exchange rates. AIG-FP provided us with daily observations on spot, 1-, 2-, and 3-month forward mid rates for EM20 currencies, many of which date back to as early as the late 1990s. The last observation is for April 19, 2010. We also obtained, via *Datastream*, the WM/Reuters Historic Rate Data on spot and forward rates for a large set of countries including G9 since December 31, 1996 as well as EM20 (from December 31, 1996 for a small subset and from 2004 for the rest of the 20 EM currencies). Unlike the AIG-FP data, the WM/Reuters data have bid and offer rates in addition to mid rates[1] and can be updated to the latest date. Both sources provide daily observations for virtually all weekdays (literally all weekdays, in the case of WM/Reuters) including national holidays, because exchange rates can be sampled from multiple international financial centers. For example, there is an observation on the JPY/USD exchange rate for Wednesday, April 29, 2009 (a Japanese national holidy).

However, observations are available for (virtually) all weekdays, only because of repetitions. For example, the exchange rate values reported for December 25 can be the same as those reported for the most recent pre-Christmas weekday. The G9 in the WM/Reuters data have very few repetitions, about 1% of weekdays. Those repetitions are probably for weekdays that are not a business day, such as December 25 when global financial centers are all closed. Regarding EM20, for both AIG-FP and WM/Reuters, observations after excluding repetitions are relatively scarce for a small subset of currencies for several years. Also, although very rare except for IDR for January 14, 2003 through June 1, 2007 and TRY for November 29, 2000 through January 24, 2001 in WM-Reuters data, the forward rates are equal to the spot rate that is not constant over time. Appendix Table 1 reports the number of non-repetitive observations (observations after removing: repeated observations[2] and those with the forward rates being mere copies of the spot rate) by year for EM20. It shows that the two data sources, when both are available, provide similar coverage,

[1] In very rare cases, the bid rate is greater than the offer rate. For those cases we change the bid and offer rates so that the mid rate remains the same and the bid-offer spread as a ratio of the mid rate is some prescribed value (2 basis points for EM20 and 1 basis point for G9).

[2] An observation for the day is deemed a repetition if the values of the three forward rates (1-, 2- and 3-month) are the same as those from the previous weekday. The criterion would be stricter if we also required the spot rate to be the same as that from the previous weekday. But then the observation for the day would not be a repetition if (as occurs in the WM/Reuters data for, e.g., TRY for 2001) the spot rate is updated for the day but the forward rates are not. This leads to an erroneous calculation of the carry (the forward premium).

except for TRY in 1997-1999 and particularly 2002 (when WM/Reuters has more observations) and IDR (AIG-FP has more).

Since AIG-FP covers longer periods than WM/Reuters, we take the AIG-FP data to be the primary data source for EM20. There can be pros and cons about use of repeated observations. Exchange rate values in data are carried over from the previous business day, maybe because the market didn't show much movements (e.g., ARS and CNY under the (virtual) fixed exchange rate regime), or maybe because the market was closed or the liquidity was severely limited. Since it would be impossible or very time-consuming for us to go to each incidence of repeated observations and determine which is the case, we decided to exclude, for the most part, repeated observations. Exceptions are:

(a) (Importation from WM-Reuters) There are weekdays for which AIG-FP does not provide non-repetitive observations but WM/Reuters does. We assume that they are business days, with some financial centers providing the exchange rate information. We import those WM/Reuters observations for those weekdays. This occurs primarily for TRY for 1997-1999 and 2002.

(b) (Retention of repeated observations) All the daily observations from AIG-FP are kept for the following currencies and periods:

ARS under the (credible) fixed exchange rate regime (until the end of September 2000),
CNY until the end of August 2003 (when the spot rate was virtually fixed),
TRY from June to November 2001, and
CLP from January 1998 to May 2000.

TRY and CLP in AIG-FP have only one observation (in the case of TRY) or only several (CLP) for those indicated months. Even for those months, the last weekday of the month is sampled in data. For this reason we supposed that the reason for the infrequency of observations was not that the markets were closed.

The last day in the AIG-FP data on EM20 is April 19, 2010. To extend the period to the latest date, we append to the AIG-FP data the non-repetitive observations from WM/Reuters for observation dates after April 19, 2010. The daily observations created this way are our Price File for EM20.

For G9, the Price File is the non-repetitive daily observations from WM/Reuters.

### A.2. A Matrix of Daily Observations

We write $F_{jt}$ for the $j$-month forward rate and $S_t$ for the spot rate on observation date $t$, stated in the foreign currency unit per USD. For each currency, the Price File provides a matrix of five columns whose typical row is $(t, S_t, F_{1t}, F_{2t}, F_{3t})$. The set of observation dates and hence the number of rows differ across currencies. From the Delivery Date File and the Price File we create a matrix for the same set of observation dates in the Price File. Its typical row is

$$t\,,\ DEL_{0t}\,,\ S_t\,,(F_{jt}\,,DEL_{jt}\,,\ OBS_{jt}\,,\ S_{OBS_{jt}}),\ \ j=\ 1, 2, 3. \qquad \text{(A1)}$$

The excess return from a $j$-month forward contract traded on date $t$ is calculated as $F_{jt}/S_{OBS_{jt}}-1$ and the carry on date $t$ is $F_{jt}/S_t-1$.

For each given observation $t$ in the Price File, we can easily obtain ($S_t\,,F_{jt}$) from the Price File and ($DEL_{0t}\,,DEL_{jt}$) from the Delivery Date File (which covers all weekdays). Far less straightforward is to determine $OBS_{jt}$. We first obtain from the Price File the first and last observation dates for which the spot rate is available. Then turn to the Delivery Date File to find the associated first and last spot delivery dates (delivery dates for spot contracts). Hereafter we temporarily drop the subscript $j$ for the forward contract in question. The following steps determine $OBS_t$ for each observation date $t$ in the Price File.

1. From the Delivery Date File, obtain $DEL_t$ from the record corresponding to $t$.
2. If $DEL_t$ is earlier than the first spot delivery date or later than the last spot delivery date just defined, we declare that $OBS_t$ and $S_{OBS_t}$ are not available, by assigning them the missing value. Otherwise, proceed as below.
3. From the Delivery Date File, we look for observation dates whose spot delivery date is $DEL_t$. The following exhausts all the possible cases.
   (a) There is only one such date in the Delivery Date File (i.e., the set $\{s\mid DEL_{0s}=DEL_t\}$ is a singleton). (An example in the JPY delivery schedule shown in Section 1 above is $t=$ March 26, 2009 with $DEL_{1t}=$ April 30. There is only one observation day, April 27, whose spot delivery date is April 30.) We turn to the Price File. There are two possibilities.
      i. If the Price File has an observation corresponding to that date, we determine $OBS_t$ to be this date. (In the current example, if the Price File has April 27, then $OBS_{1t}$ = April 27.)
      ii. Otherwise, we determine $OBS_t$ to be the earliest observation date after that date in the Price File. (In the current example, if the Price File has April 28 but not April 27, then $OBS_{1t}$ = April 28.) The underlying trading strategy is to receive the counter currency on $DEL_t$, hoard or lend the currency, and

(b) There are multiple such dates in the Delivery Date File. (An example in the JPY schedule shown in Section 1 is $t =$ March 30, 2009 with $DEL_{1t} =$ May 1. There are two observation dates, April 28 and April 29, whose spot delivery date is May 1.) From those multiple observation dates we select the set of dates, each of which has an observation in the Price File. There are two possibilities.

i. This set is not empty. $OBS_t$ is the last date of this non-empty set. (In the current example, if the Price File has both April 28 and April 29, then $OBS_{1t}$ = April 29.)

ii. This set is empty. We determine $OBS_t$ to be the earliest observation date after the last of those multiple observation dates in the Price File. (In the current example, if the Price File has neither April 28 nor April 29 but has April 30, then $OBS_{1t}$ = April 30). The underlying trading strategy is the same as in (a-ii).

(c) There is no such date in the Delivery Date File. (This occurs for IDR, PHP, CNY, TWD, MXN, ARS, and JPY a very few times in the periods shown in Table 1.) We turn to the earliest spot delivery date after $DEL_t$ in the Delivery Date File such that the associated observation dates in the Delivery Date File have at least one corresponding observation in the Price File. We determine $OBS_t$ to be the last date of those corresponding observations in the Price File. (If $DEL_t$ is the last spot delivery date defined above, then this procedure is infeasible, but this did not arise in our data.) This procedure would correctly identify $OBS_t$ if the true delivery date is not $DEL_t$ (as given in the Delivery Date File) but the spot delivery date as determined above. If the true delivery date is before this spot delivery date, the underlying investment strategy is as described for case (a-ii) and (b-ii). Otherwise, the strategy involves borrowing the counter currency on the spot delivery date until the true delivery date.

The spot rate on $OBS_t$ thus determined in cases (a)-(c) is available because $DEL_t$ is between the first and the last spot delivery dates defined above.

The data challenges identified in (a-ii) and (b-ii) can occur because the Price File does not have observations on all business days. The date misalignment described in (c) can occur perhaps because there was an unscheduled holiday that was added between the initial establishment of the forward transaction or its delivery. In the case of IDR the delivery schedule is also complicated by the need to observe Singapore holidays for the NDF (non-deliverable forward) market.

**A.3. The Monthly File**

To create monthly observations on so-called end/end deals in which the delivery date for the forward contract is the last business day of the month, we extract, for each month in the matrix of daily observations just described, the row or observation date whose $DEL_{jt}$ is the latest day of the month. (If there are multiple observation dates, we pick the row corresponding to the latest observation date.) The convention in the forward market is that this choice of the observation date does not depend on the tenor (spot, 1-, 2-, or 3-month forward) of the contract (although it can depend on the currency). The JPY example of Section 1 of this appendix illustrate this.

If the first daily observation of the spot and forward rate is, for example, December 31, 1996 (as in the WM/Reuters data), the first monthly excess return observation is from January to February 1997. This is because to calculate the December 1996 to January 1997 return we need to observe the 1-month forward rate on one or two business days prior to December 31, 1996.

In the monthly file thus created, let $t(m)$ be the observation date of month $m$. To use the JPY example, $t(m)$ = March 27, 2009 for $m$ = March 2009 and $t(m+1)$ = April 27, 2009, provided that the Price File has those observation dates. If the Delivery Date File had no date misalignment of the sort described in case (c) above and if the Price File had for each month an observation whose $DEL_{1t}$ is the last business day of the month, then the way the monthly file is created ensures that, for any month $m$ in the monthly file, we have:

$$DEL_{j,t(m)} = DEL_{0,t(m+j)} \quad \text{for} \quad j = 1, 2, 3. \tag{A2}$$

In the current JPY example, $DEL_{1,t(m)}$ =April 30 and $DEL_{0,t(m+1)}$ = April 30, as required by (A2). Under the procedure described in Section 2 of this appendix for determining $OBS_{jt}$, (A2) implies

$$OBS_{j,t(m)} = t(m+j) \quad \text{for} \quad j = 1, 2, 3. \tag{A3}$$

In the example, indeed, $OBS_{1,t(m)} = t(m+1)$ = April 27, 2009.

To understand the role played by (A2) and (A3), consider an investor who opened a 1-month forward long position in month $m$ (say, March 2009) on $t(m)$ (March 27, 2009), deliverable on $DEL_{1,t(m)}$ (April 30). To maintain (or "roll") the forward position, the investor must sell spot the counter currency she receives on $DEL_{1,t(m)}$ and buy forward the currency. The spot and forward legs of this transaction can be arranged on the same day ( $OBS_{1,t(m)}$ , April 27) if (A3) holds. (An FX swap can be used to execute both legs simultaneously.) (A2) ensures that a delivery of the counter currency promised in the spot leg is provided by the existing forward position created on $t(m)$ (March 27).

Because of the possible date misalignment in the Delivery Date File and missing business days in the Price File, conditions (A2) and (A3) can fail. (In the current JPY example with $m$ = March 2009, if the Price File does not have April 27 but has April 24 (so case (a-ii) applies here), both (A2) and (A3) fail with $t(m+1)$ = April 24, and $D_{0,t(m+1)}$ = April 28, $OBS_{1,t(m)}$ = April 28.) For EM20, the conditions for $j=1$ fail in 88 cases (currency-months) out of 3,197 cases. For those problem cases, we redefine $OBS_{j,t(m)}$ ( $j=1$, 2, 3) this time by (A3), so the spot and forward legs can still be arranged on the same day. However, since the delivery date $DEL_{j,t(m)}$ of the existing forward position is before or after the spot delivery date of $D_{0,t(m+j)}$ , the investor needs to borrow or lend the forward currency to bridge the gap. The G9 monthly file has no such problem cases.

### A.4. Variables in the Monthly File

An Excel file called "Gilmore_Hayashi_monthly_FX_file.xls" has been created by the procedure detailed above. It has 52 sheets grouped into three sets of currencies.

(a) 20 sheets bearing EM20's acronyms --- "TWD", "THB", "ZAR", "TRY", "PHP", "KRW", "CNY", "IDR", "PLN", "CZK", "CLP", "MXN", "SKK", "HUF", "COP", "ARS", "INR", "BRL", "ILS", and "RUB" --- have the following series. The data source is AIG-FP supplemented by WM-Reuters as described in Section 1 of this appendix.

column 1 (labelled "year-month"): year and month of the month (e.g., 201004),
column 2 ("date"): observation date for the end/end deal,
column 3 ("eom_obs"): 1 if "date" is the last observation day of the month in the Price File, 0 otherwise,
column 4 ("DEL0"): delivery date of spot contracts traded on "date",
column 5 ("S"): mid spot rate observed on "date",
column 6 ("F1"): mid one-month forward rate observed on "date",
column 7 ("F2"): mid two-month forward rate observed on "date",
column 8 ("F3"): mid three-month forward rate observed on "date",
column 9 ("DEL1"): delivery date of one-month forward contracts traded on "date",
column 10 ("OBS1"): observation date for spot contracts deliverable on "DEL1",
column 11 ("S_OBS1"): mid spot rate observed on "OBS1",

column 12 (“DEL2”): delivery date of two-month forward contracts traded on “date”,

column 13 (“OBS2”): observation date for spot contracts deliverable on “DEL2”,

column 14 (“S_OBS2”): mid spot rate observed on “OBS2”,

column 15 (“DEL3”): delivery date of three-month forward contracts traded on “date”,

column 16 (“OBS3”): observation date for spot contracts deliverable on “DEL3”,

column 17 (“S_OBS3”): mid spot rate observed on “OBS3”,

column 18 (“FLAG1”): flag for “OBS1”. 1 if case (a-i) described in Section 2 above, 2 if (a-ii), 3 if (b-i), 4 if (b-ii), 5 if (c), 999 if “DEL1” is after the last spot delivery date defined in Section 2,

column 19 (“FLAG2”): flag for “OBS2”,

column 20 (“FLAG3”): flag for “OBS3”,

column 21 (“signal_obs_date”): signal observation date defined in Section IV.B of the text, common to all constituent currencies,

column 22 (“too_early”): 1 if “date” is on or earlier than “signal_observation_date”, 0 otherwise,

column 23 (“actual_signal_date”): date the signal (i.e., the carry) is actually observed,

column 24 (“S_signal”): mid spot rate on “signal_date”,

column 25 (“F1_signal”): mid one-month forward rate on “signal_date”,

column 26 (“F2_signal”): mid two-month forward rate on “signal_date”,

column 27 (“F3_signal”): mid three-month forward rate on “signal_date”,

column 28 (“last_bus_date”): the last observation day of the month in the Price File, i.e., the date for which “eom_obs” equals 1,

column 29 (“S_eom”): mid spot rate on “last_bus_date”,

column 30 (“F1_eom”): mid one-month forward rate on “last_bus_date”,

column 31 (“F2_eom”): mid two-month forward rate on “last_bus_date”,

column 32 (“F3_eom”): mid three-month forward rate on “last_bus_date”.

The “eom” information (columns 28-32) is included only because the usual way in the academic literature to calculate the excess return utilizes them; the one-month excess return from month $m-1$ to $m$ is usually calculated as: F1_eom for month $m-1$ less S_eom for month $m$.

(b) 12 sheets bearing G9’s acronyms --- “AUD”, “CAD”, “JPY”, “NZD”, “NOK”, “SEK”, “CHF”, “GBP”, “EUR”, “DEM”, “FRF”, and “ITL” --- have the following 54 series. The data source is WM-Reuters.

column 1 (“year-month”): year and month of the month (e.g., 201004),

column 2 (“date”): observation date for the end/end deal, column 3 (“eom_obs”): 1 if “date” is the last observation day of the month in the Price File, 0 otherwise,

column 4 (“DEL0”): delivery date of spot contracts traded on “date”,

column 5 (“S_mid”): mid spot rate observed on “date”,

column 6 (“F1_mid”): mid one-month forward rate observed on “date”,

column 7 (“F2_mid”): mid two-month forward rate observed on “date”,

column 8 (“F3_mid”): mid three-month forward rate observed on “date”,

column 9 (“S_bid”): bid spot rate observed on “date”,

column 10 (“F1_bid”): bid one-month forward rate observed on “date”,

column 11 (“F2_bid”): bid two-month forward rate observed on “date”,

column 12 (“F3_bid”): bid three-month forward rate observed on “date”,

column 13 (“S_offer”): offer spot rate observed on “date”,

column 14 (“F1_offer”): offer one-month forward rate observed on “date”,

column 15 (“F2_offer”): offer two-month forward rate observed on “date”,

column 16 (“F3_offer”): offer three-month forward rate observed on “date”,

column 17 (“DEL1”): delivery date of one-month forward contracts traded on “date”,

column 18 (“OBS1”): observation date for spot contracts deliverable on “DEL1”,

column 19 (“S_mid_OBS1”): mid spot rate observed on “OBS1”,

column 20 (“S_bid_OBS1”): bid spot rate observed on “OBS1”,

column 21 (“S_offer_OBS1”): offer spot rate observed on “OBS1”,

column 22 (“DEL2”): delivery date of two-month forward contracts traded on “date”,

column 23 (“OBS2”): observation date for spot contracts deliverable on “DEL2”,

column 24 (“S_mid_OBS2”): mid spot rate observed on “OBS2”,

column 25 (“S_bid_OBS2”): bid spot rate observed on “OBS2”,

column 26 (“S_offer_OBS2”): offer spot rate observed on “OBS2”,

column 27 (“DEL3”): delivery date of three-month forward contracts traded on “date”,

column 28 (“OBS3”): observation date for spot contracts deliverable on “DEL3”,

column 29 (“S_mid_OBS3”): mid spot rate observed on “OBS3”,

column 30 (“S_bid_OBS3”): bid spot rate observed on “OBS3”,

column 31 (“S_offer_OBS3”): offer spot rate observed on “OBS3”,

column 32 (“FLAG1”): flag for “OBS1”. 1 if case (a-i) described in Section 2 above, 2 if (a-ii), 3 if (b-i), 4 if (b-ii), 5 if (c), 999 if “DEL1” is after the last spot delivery date defined in Section 2,

column 33 (“FLAG2”): flag for “OBS2”,

column 34 (“FLAG3”): flag for “OBS3”,

column 35 (“signal_obs_date”): signal observation date defined in Section IV.B of the text, common to all constituent currencies,

column 36 (“too_early”): 1 if “date” is on or earlier than “signal_observation_date”, 0 otherwise,

column 37 (“actual_signal_date”): date the signal (i.e., the carry) is actually observed,

column 38 (“S_signal”): mid spot rate on “signal_date”,

column 39 (“F1_signal”): mid one-month forward rate on “signal_date”,

column 40 (“F2_signal”): mid two-month forward rate on “signal_date”,

column 41 (“F3_signal”): mid three-month forward rate on “signal_date”,

column 42 (“last_bus_date”): the last observation day of the month in the Price File, i.e., the date for which “eom_obs” equals 1,

column 43 (“S_mid_eom”): mid spot rate on “last_bus_date”,

column 44 (“F1_mid _eom”): mid one-month forward rate on “last_bus_date”,

column 45 (“F2_mid _eom”): mid two-month forward rate on “last_bus_date”,

column 46 (“F3_mid _eom”): mid three-month forward rate on “last_bus_date”,

column 47 (“S_bid_eom”): bid spot rate on “last_bus_date”,

column 48 (“F1_bid _eom”): bid one-month forward rate on “last_bus_date”,

column 49 (“F2_bid _eom”): bid two-month forward rate on “last_bus_date”,

column 50 (“F3_bid _eom”): bid three-month forward rate on “last_bus_date”,

column 51 (“S_offer_eom”): offer spot rate on “last_bus_date”,

column 52 (“F1_offer _eom”): offer one-month forward rate on “last_bus_date”,

column 53 (“F2_offer _eom”): offer two-month forward rate on “last_bus_date”,

column 54 (“F3_offer _eom”): offer three-month forward rate on “last_bus_date”.

For AUD, EUR, GBP, and NZD, the exchange rate is in USD per unit of the foreign currency.

(c) 20 sheets bearing EM20’s acronyms with “_WM” added --- “TWD_WM”, “THB_WM”, “ZAR_WM”, “TRY_WM”, “PHP_WM”, “KRW_WM”, “CNY_WM”, “IDR_WM”, “PLN_WM”, “CZK_WM”, “CLP_WM”, “MXN_WM”, “SKK_WM”, “HUF_WM”, “COP_WM”, “ARS_WM”, “INR_WM”, “BRL_WM”, “ILS_WM”, and “RUB_WM” --- have 54 series with the same definitions as in (b). The data source is WM-Reuters.

**A.5. Two Excel Files to Accompany the Monthly File**

There are two Excel files to accompany “Gilmore_Hayashi_monthly_FX_file.xls”.

**“obs dates.xls”**

Has three sheets. Sheet “EM20” has the observation date for the end/end deal for EM20 currencies for each month. For example, the observation date for TWD for June 1996 is June 26, 1996. The column named "signal_obs_date" is the signal observation date for the month defined in Section IV.B of the text and also Section A.4 of this appendix. The next-to-last column reports the number of days left in the month. The last column reports the fraction of the constituent currencies whose observation date is on or after the signal observation date. It should consist of zeros. Sheet "WM Gx" has the same information for G9. Sheet "WM EM20" has the same for EM20 if the constituent currencies are those available from WM/Reuters. The information in "WM EM20" differs from that in "EM20" only because the set of currencies whose daily rate information is available. Thus "WM EM20" is not relevant for the content of the paper.

**"problem months.xls"**

Sheet "EM20" shows the same variables listed in Section A.4 of this appendix for the 88 problem cases mentioned in the last paragraph of Section A.3, except that $OBS_{j,t(m)}$ ($j = 1, 2, 3$) are before the redefinition (A3). It has twice as many rows (176 rows) as there are problem cases because each problem case involves two successive months. (Besides the first column, which shows the FX name) there are two additional columns at the end. Those columns are about the difference in weekdays between the left hand side and the right hand side of (A2) for $j = 1$. The first of the those columns is the difference if the left hand side is greater, while the second is the difference if the right hand side is greater. Sheet "WM Gx" is empty because there are no problem cases for G9. Sheet "WM EM20" (not relevant for the content of the paper) shows problem cases if WM/Reuters is the only source of the Price File.

## AppendixB: Incorporating Bid/offer Spreads

We argued in the text that the transactions cost due to bid/offer spreads is much lower than commonly supposed in the academic literature. In the first section of this appendix, we substantiate this claim by deriving a formula for the cumulative return from continued exposure to forward contracts via FX (foreign exchange) swaps. The second section of the appendix generalizes the formula to portfolios of currencies that is rebalanced monthly to arbitrarily given weights. The weights may be the same across constituent currencies as in the passive, equally-weighted strategy considered in Section III of the text, or they may be a function of the carry for currencies as in the active strategy considered in Section IV of the text. Throughout the appendix, we suppose that the duration of the forward contract is 1 month and that the unit period is a month. The base currency is taken to be USD (the U.S. dollar).

### B.1. Excess Return Calculation for a Single Currency

In this appendix, we state the exchange rate in units of the foreign currency, because that is the practice of the foreign exchange market for all EM (emerging market) currencies and for most major currencies. So let $S_t^b$ and $S_t^o$ denote the bid and offer rates in date $t$ against USD stated in units of the foreign currency in question. The spot bid/offer spread is $S_t^o - S_t^b > 0$. One gets to buy an amount $S_t^b$ of the foreign currency for selling 1 unit of USD, and $1/S_t^o$ units of USD for selling 1 unit of the foreign currency. The mid rate is the arithmetic average of the bid and offer rates, i.e., $S_t \equiv (S_t^b + S_t^o)/2$. So we have $S_t^o > S_t > S_t^b$.

It is also a practice of the foreign exchange market to express the (outright) forward rate as the sum of the spot rate and the forward premium. The latter is called the "forward points". If $P_t^b$ and $P_t^o$ denote the bid and offer values of the forward points, the forward bid and offer rates are $F_t^b \equiv S_t^b + P_t^b$ and $F_t^o \equiv S_t^o + P_t^o$. Since the offer forward points are always greater than the bid and since $S_t^o > S_t^b$, we have $F_t^o > F_t > F_t^b$ where $F_t \equiv (F_t^b + F_t^o)/2$ is the mid forward rate, and the bid/offer spread should be wider for the forward contract than for the spot contract.

An FX swap is a contract to buy spot an amount of currency at an agreed rate (the "spot leg"), and simultaneously resell the same amount of currency for a later date (1 month hence in our case) also at an agreed forward rate (the "forward leg"). There are "uneven" (or "mismatched" or "non-round") swaps whereby the amounts vary on each leg of the swap. We assume that the amount is the same in both legs for the most part. Toward the end of this section, we consider uneven FX swaps. The rate in the spot leg is usually the current mid rate, which is what we assume in all our calculations. Therefore, the forward rate in the forward leg, which we denote $\tilde{F}_t$, is $\tilde{F}_t \equiv S_t + P_t^b$. It can be written as[3]

$$\tilde{F}_t = F_t - \frac{1}{2}\left[\left(F_t^o - F_t^b\right) - \left(S_t^o - S_t^b\right)\right] = \left(1 - \frac{1}{2}\frac{\left(F_t^o - F_t^b\right) - \left(S_t^o - S_t^b\right)}{F_t}\right)F_t . \tag{B1}$$

By construction, we have $F_t^o > F_t > \tilde{F}_t > F_t^b$.

Consider a USD investor who takes long positions on 1-month forward contracts over $n$ consecutive months from month 0 to $n$, with an initial wealth of USD $A_0$ ($A_0$ U.S. dollars). The position is "long" because the investor promises to *buy* the foreign currency or sell USD. We now describe the rolling operation involving FX swaps that underlies our calculation of the excess return with bid/offer spreads. Let $r_t$ be the 1-month USD interest rate from the end of month $t$ to $t+1$. For concreteness, let's say the foreign currency is ZAR (South African Rand).

(a) At the end of month 0, the investor opens a forward position by an outright forward contract. She buys 1 month forward ZAR (i.e., sells 1 month forward USD). The notional, i.e., the amount or volume of the position, measured in USD is chosen to be USD $A_0(1+r_0)$. The outright forward rate is the bid rate $F_0^b$ (because the investor is promising to sell USD/buy ZAR), so the ZAR amount of the position is $X_0 \equiv A_0(1+r_0)F_0^b$. At the same time, the USD amount $A_0$ is invested in the USD 1-month money market instrument.

(b) At the end of month 1, the investor collects USD $A_0(1+r_0)$ from the money market investment. This USD amount matches the ZAR amount $X_0 = A_0(1+r_0)F_0^b$, that is, it is just enough to pay for the ZAR delivery. With this ZAR amount in hand, the investor carries out an FX swap. In the spot leg of the FX swap, the investor buys spot USD (sells spot ZAR) at the mid rate $S_1$ to obtain USD $A_1 = X_0 / S_1$, which is invested in the USD 1-month money market instrument. In the forward leg, the investor sells forward this USD amount $X_0 / S_1$ to create a forward position of ZAR $(X_0 / S_1)\tilde{F}_1$. Thus the current forward position has been rolled over via the FX swap. In addition, to take account of the interest income to be collected in the next month from the USD 1-month money market investment, the investor opens an additional and new forward position by an outright forward contract. As in the initial period, the outright forward rate is the bid rate $F_1^b$, not the more favourable rate of

[3] Since $F_t^b = S_t^b + P_t^b$, we have $\tilde{F}_t \equiv S_t + P_t^b = (1/2)(S_t^o + S_t^b) + (F_t^b - S_t^b) = (1/2)(S_t^o - S_t^b) + F_t^b$. This equals (B1) because $F_t = (1/2)(F_t^o + F_t^b)$ or $F_t^b = F_t - (1/2)(F_t^o - F_t^b)$.

$\tilde{F}_1$, because this is a newly opened position. So if $Z_1$ is the ZAR amount of this additional position, its USD amount is $Z_1 / F_1^b$. The total forward position carried over to the next period is ZAR $X_1 = (X_0 / S_1)\tilde{F}_1 + Z_1$. In order for the principal and the interest that the investor receives in the next period from the USD investment to match this ZAR amount, the size of the new ZAR position $Z_1$ must satisfy

$$(1+r_1)A_1 = \frac{X_0}{S_1} + \frac{Z_1}{F_1^b}. \tag{B2}$$

(c) More generally, at the end of each interim month $t$ $(=1,2,..,n-1)$, given the forward position of ZAR $X_{t-1}$, the investor repeats the same transaction described by three equations

$$A_t = \frac{X_{t-1}}{S_t},\ X_t = \frac{X_{t-1}}{S_t}\tilde{F}_t + Z_t,\ \text{and}\ (1+r_t)A_t = \frac{X_{t-1}}{S_t} + \frac{Z_t}{F_t^b}. \tag{B3}$$

The first of these three equations describes the spot leg of the FX swap. The second equation says that the new position consists of the position created by the forward leg of the FX swap and a position due to a new outright forward contract. The third equation is a matching requirement that the size of the new position be equal to that of the current USD 1-month investment.

(d) In the final month $t = n$, the investor closes out or unwinds the forward position that was carried over from the previous month. That is, the investor receives a delivery of ZAR $X_{n-1}$ and sell spot this amount for USD $A_n = X_{n-1} / S_n^o$. The spot rate is the offer rate $S_n^o$ because the investor is selling ZAR/buying USD. The cumulative gross total (i.e., cum interest) USD return over the $n$ period is $A_n / A_0$. This completes our description of the rolling operation.

The three equations in (B3) together yield a difference equation in $X_t$:

$$X_t = (1+r_t)\frac{X_{t-1}}{S_t}\tilde{F}_t - \left(\frac{\tilde{F}_t}{F_t^b} - 1\right)Z_t = (1+r_t)\frac{X_{t-1}}{S_t}\hat{F}_t, \tag{B3'}$$

where (with $\tilde{F}_t$ the forward rate in the forward leg defined in (B1) ) the applicable forward rate $\hat{F}_t$ is defined as[4]

[4] To derive (B3') with (B4), note that the last equation of (B3) implies $Z_t / F_t^b = r_t A_t$. Also, from the previous footnote, $\tilde{F}_t = (1/2)(S_t^o - S_t^b) + F_t^b$.

$$\hat{F}_t \equiv \tilde{F}_t - \left(\frac{\tilde{F}_t}{F_t^b} - 1\right)\frac{Z_t}{(1+r_t)A_t} = \left(1 - \frac{r_t}{1+r_t}\frac{\frac{1}{2}(S_t^o - S_t^b)}{\tilde{F}_t}\right)\tilde{F}_t. \tag{B4}$$

By construction, we have $F_t^o > F_t > \tilde{F}_t > \hat{F}_t > F_t^b$.

With the initial condition of $X_0 = A_0(1+r_0)F_0^b$ and taking into account that in the final month the ZAR position $X_{n-1}$ is converted into USD at the offer rate $S_n^o$, the cumulative gross total USD return, $A_n / A_0$, can be calculated by the recursion (B3') as[5]

$$A_n / A_0 = (1+r_0)\cdots(1+r_{n-1})\frac{F_0^b}{S_1}\times\frac{\hat{F}_1}{S_2}\times\cdots\times\frac{\hat{F}_{n-2}}{S_{n-1}}\times\frac{\hat{F}_{n-1}}{S_n^o}. \tag{B5}$$

Therefore, the expression for the cumulative gross excess return with transactions costs that we have been seeking is

$$\text{Cumulative gross excess return with FX swaps} = \frac{F_0^b}{S_1}\times\frac{\hat{F}_1}{S_2}\times\cdots\times\frac{\hat{F}_{n-2}}{S_{n-1}}\times\frac{\hat{F}_{n-1}}{S_n^o}. \tag{B6}$$

In the above foreign exchange operation, the forward position (excluding the portion corresponding to the interest) is rolled over in the interim months. If, as assumed in most of the academic literature, the forward position is closed and then newly opened in each month, the applicable forward rate (at which the investor buys ZAR forward) in the interim month is now the bid rate $F_t^b$ for all months and the applicable spot rate (at which the investor sells spot ZAR for USD) in the interim month is the offer rate. Thus, the formula for the cumulative gross excess return becomes

$$\text{Cumulative gross excess return without FX swaps} = \frac{F_0^b}{S_1^o}\times\frac{F_1^b}{S_2^o}\times\cdots\times\frac{F_{n-2}^b}{S_{n-1}^o}\times\frac{F_{n-1}^b}{S_n^o}. \tag{B7}$$

If we ignore transactions costs by setting the spot and forward bid/offer spreads to zero and thus assuming that all the transactions occur at mid rates, the cumulative gross excess return becomes

$$\text{Cumulative gross excess return without transactions costs} = \frac{F_0}{S_1}\times\frac{F_1}{S_2}\times\cdots\times\frac{F_{n-2}}{S_{n-1}}\times\frac{F_{n-1}}{S_n}. \tag{B8}$$

We could define the *transactions cost per unit period* as the $n$-th root of the ratio of the cumulative gross excess return without bid/offer spreads to one with bid/offer spreads, less unity. If

[5] As mentioned in footnote 22 of the text, the formula has the mid rate $S_n$ in place of the offer rate $S_n^o$ if the rate is taken from the NDF (non-deliverable forward) market.

FX swaps is utilized, the ratio in the definition is the ratio of (B8) to (B6), so the per-unit period transactions cost is

$$\left[\text{ratio of (A2.8) to (A2.6)}\right]^{1/n} - 1 = \left[\left(\frac{F_0}{F_0^b}\right) \times \left(\frac{S_n^o}{S_n}\right) \times \prod_{t=1}^{n-1}\left(\frac{F_t}{\hat{F}_t}\right)\right]^{1/n} - 1. \qquad \text{(B9)}$$

A series of approximations yields that the transactions cost per unit period is approximately equal to[6]

$$\frac{1}{n}\left[\frac{1}{2}\left(\frac{F_0^o - F_0^b}{F_0} + \frac{S_n^o - S_n^b}{S_n}\right)\right] + \frac{n-1}{n}\left[\frac{1}{n-1}\sum_{t=1}^{n-1}\frac{1}{2}\frac{\left(F_t^o - F_t^b\right) - \left(S_t^o - S_t^b\right)}{F_t}\right]$$

$$+ \frac{n-1}{n}\left[\frac{1}{n-1}\sum_{t=1}^{n-1}\frac{r_t}{1+r_t}\frac{\frac{1}{2}\left(S_t^o - S_t^b\right)}{F_t}\right]. \qquad \text{(B10)}$$

The first term represents the entry and exit costs, each equalling half times the relevant bid/offer spread. It is divided by $n$ (the investment horizon) because those costs are paid only once. The second term is the average cost of rolling the forward position. The third term comes about because the interest component of the position needs to be opened anew in every interim month.

We now consider the case in which "uneven" FX swaps are allowed. With uneven swaps, the formulas we have derived become simpler. Since the forward leg can be expanded to cover the interest component, there is no need to open a new position by an outright forward contract; the investor can take advantage of the more favourable rate $\tilde{F}_t$ in month $t$ for the whole of the position. Therefore, $\tilde{F}_t$ replaces $F_t^b$ in the last of the three equations in (B3). Consequently, $\tilde{F}_t$ replaces $\hat{F}_t$ in the difference equation (B3') and also in the cumulative returns formulas (B5) and (B6). Indeed, the formula (16) in the text reflects this substitution. The formula for the approximate transactions cost (B10) simplify as (17) of the text, with the interest term (the third term) in (B10) dropping out.

In all these discussions, special attention should be paid to CNY (Chinese Yuan). Since the local convention is to quote a single rate for the spot rate and to express the outright forward rate as the sum of this single spot rate (call that $S_t$) and forward points, $F_t^b = S_t + P_t^b$ instead of

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6 To derive (B10), we use (B1), (B4), and the fact that $S_t^o - S_t = (1/2)(S_t^o - S_t^b)$ and $F_t - F_t^b = (1/2)(F_t^o - F_t^b)$. The approximations used are: for $a$ and $b$ close to each other, $c \approx \frac{1}{n}\log(a/b)$ if $c \equiv \left(\frac{a}{b}\right)^{1/n} - 1$, $\log(a/b) \approx \frac{a-b}{b}$, and $\frac{1}{a} \approx \frac{1}{b}$.

$F_t^b = S_t^b + P_t^b$ as in the second paragraph of this section. Recalling that the definition of $\tilde{F}_t$ (the forward rate in the forward leg of an FX swap and also the applicable rate when uneven FX swaps are allowed) is given by $\tilde{F}_t \equiv S_t + P_t^b$, we have $\tilde{F}_t = F_t^b$, which also means that $\hat{F}_t$, the applicable forward rate with swaps with even amounts, too reduces to $F_t^b$. Furthermore, since the spot exchange data on CNY is from the NDF (non-deliverable forward) market, the applicable spot rate is that single spot rate $S_t$. Put differently, for CNY, rolling and opening/unwinding a position cost the same in data (although in practice, their costs could differ because the spot rate and forward points are determined at different times on the day).

To close this section, we note for our data that the approximation for the per-period transactions cost — (B10) for the case of "even" FX swaps and (17) in the text for "uneven" swaps — is almost exact and that whether uneven swaps are allowed or not makes very little difference for the transactions cost. For each of the two cases (even and uneven swaps), there can be four different ways to calculate the transactions cost: (a) the exact formula (B9) (with $\tilde{F}_t$ replacing $\hat{F}_t$ in the case of uneven swaps), (b) the difference in the geometric mean of the gross excess return with and without transactions cost, (c) the difference in the arithmetic mean, and (d) the approximation formula (B10) (with the third term dropped for the uneven case). In our data, formulas (a)-(c) give virtually the same estimate of the annualized transactions cost, differing from each other in less than 1 basis point, for almost all of the EM and major currencies, particularly when the investment horizon $n$ is more than a couple of years, and the basis point estimate does not depend on whether uneven swaps are allowed or not. Formula (d) sometimes gives somewhat different estimates, but the discrepancy gets very small when averaged across constituent currencies. As an illustration, for $n$ = 60 months, the annualized transactions cost estimate averaged across the 20 EM currencies is the same (42 basis points per year) for all eight formulas.

**B.2. Portfolio Excess Returns**

To handle portfolios that takes long positions in multiple foreign currencies, we add subscript $j$ for currency $j = 1,2,...,J$, where $J$ is the number of constituent currencies ($J$ can depend on time $t$). So, for example, $S_{jt}$ is the spot mid rate of currency $j$ against the base currency, stated in units of currency $j$, at the end of month $t$. As before, the investment horizon is $n$. For interim month $t$ ($t = 1,2,...,n-1$), the additional notation is

$X_{j,t-1}$ = position in foreign currency $j$, stated in the foreign currency unit, determined at the end of month $t-1$ and carried over to month $t$,

$Y_{jt}$ = amount, stated in the foreign currency unit, to unwind at the end of month $t$,

$Z_{jt}$ = amount, stated in the foreign currency unit, to newly open at the end of month $t$.

$Y_{jt}$ and $Z_{jt}$ are required to be nonnegative. The portion $Y_{jt}$ of the existing position in currency $j$ is closed out, and the offer rate $S^o_{jt}$ applies. The amount to roll for currency $j$ is $X_{j,t-1} - Y_{jt}$. As in the case of a single currency, the favourable rate $\tilde{F}_{jt}$ applies to rolled positions, so the position in the foreign currency unit to be carried over to the next month $t+1$ is $(X_{j,t-1} - Y_{jt})\tilde{F}_{jt} / S_{jt}$. The three equations in (B3), which assume that uneven FX swaps are not allowed, can be extended to multiple currencies as

$$A_t = \sum_{j=1}^{J} \left( \frac{X_{jt} - Y_{jt}}{S_{jt}} + \frac{Y_{jt}}{S^o_{jt}} \right), \tag{B11a}$$

$$X_{jt} = \left( X_{j,t-1} - Y_{jt} \right) \frac{\tilde{F}_{jt}}{S_{jt}} + Z_{jt} \qquad \text{for} \qquad j = 1,2,\ldots,J\ , \tag{B11b}$$

$$(1+r_t) A_t w_{jt} = \frac{X_{j,t-1} - Y_{jt}}{S_{jt}} + \frac{Z_{jt}}{F^b_{jt}} \qquad \text{for} \qquad j = 1,2,\ldots,J\ , \tag{B11c}$$

for $t = 1,2,\ldots,n-1$. Here, $w_{jt}$ is currency $j$'s weight in the portfolio of forward long positions. (B11) reduces to (B3) if $J = 1$, $Y_{jt} = 0$, and $w_{jt} = 1$.

In the interim month $t$, Given the portfolio carried over from month $t-1$ and given the exchange rates, the system (B11) has $3J+1$ unknowns $(A_t, Y_{1t}, \ldots, Y_{Jt}, Z_{1t}, \ldots, Z_{Jt}, X_{1t}, \ldots, X_{Jt})$ but only $2J+1$ equations. Because of the bid/offer spreads, it is not to the investor's advantage to close out some portion of the position and at the same time create a new position for the same currency. To be more precise, suppose (B11) has a solution $(A_t, Y_{1t}, \ldots, Y_{Jt}, Z_{1t}, \ldots, Z_{Jt}, X_{1t}, \ldots, X_{Jt})$ with $Y_{jt} > 0$ and $Z_{jt} > 0$ for some currency. Then it is possible to find an alternative solution $(A_t', Y_{1t}', \ldots, Y_{Jt}', Z_{1t}', \ldots, Z_{Jt}', X_{1t}', \ldots, X_{Jt}')$ with a dominating portfolio, that is, with $X_{jt}' > X_{jt}$ for all currency $j$. Therefore, either $Y_{jt}$ or $Z_{jt}$

is zero, which furnishes additional $J$ equality conditions.[7] This provides a difference equation, a mapping from $(X_{1,t-1}, X_{2,t-1},..., X_{J,t-1})$ to $(X_{1t}, X_{2t},..., X_{Jt})$.

In the initial month $t = 0$, the investor opens a position by an outright forward contract for each currency. If $w_{j0}$ is the weight for currency $j$, the portfolio to be carried over to the first interim month $t = 1$ is

$$(X_{10}, X_{20},..., X_{J0}) = \left((1+r_0)A_0 w_{10} F_{10}^b, (1+r_0)A_0 w_{20} F_{20}^b,..., (1+r_0)A_0 w_{J0} F_{J0}^b\right), \quad \text{(B12)}$$

where, as in the single-currency case, the scalar $A_0$ is the initial USD wealth. Taking this as the initial condition, we can use the recursion described in the previous paragraph to obtain $(X_{1,n-1}, X_{2,n-1},..., X_{J,n-1})$, the portfolio to be carried into the final investment month $n$ when the position is closed out. The USD value of the portfolio when closed out is

$$A_n = \sum_{j=1}^{J} \frac{X_{j,n-1}}{S_{jn}^o}. \quad \text{(B13)}$$

Given the initial USD wealth $A_0$ and the terminal wealth $A_n$, we can define the cumulative gross total and excess returns and the transactions cost exactly as in the single-currency case of the previous section. We used the 1-month LIBOR rate at the end of month $t$ for the interest rate $r_t$ in the above formulas. The value of the interest rate hardly affects the excess return.

[7] Finding the corner — which one, $Y_{jt}$ or $Z_{jt}$, is zero for each $j$ — is accomplished by solving a linear programming problem, in which the objective function is a weighted sum over $j$ of $X_{jt}$ and the constraints are (B11) and $Y_{jt} \geq 0$ and $Z_{jt} \geq 0$. We used the "linprog" function of Matlab (version R2010b) to find the solution. Different choices of the weight vector in the objective function should result in the same corner (and indeed they do in our computations) as long as the weight is positive for all $j$.

## Appendix Table 1: Number of Non-Repetitive Daily Observations

| | TWD | | THB | | ZAR | | TRY | | PHP | | KRW | | CNY | | IDR | | PLN | | CZK | | CLP | | MXN | | SKK | | HUF | | COP | | ARS | | INR | | BRL | | ILS | | RUB | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1996 | 139 | 1 | 149 | 1 | 147 | 1 | 146 | 1 | 59 | 1 | 20 | 0 | 19 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1997 | 219 | 196 | 255 | 251 | 245 | 256 | 235 | 255 | 239 | 249 | 235 | 0 | 193 | 0 | 253 | 253 | 222 | 0 | 208 | 256 | 164 | 0 | 198 | 255 | 138 | 0 | 19 | 47 | 0 | 0 | 1 | 0 | 0 | 47 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1998 | 243 | 252 | 256 | 258 | 247 | 258 | 237 | 255 | 216 | 256 | 232 | 0 | 201 | 0 | 255 | 258 | 252 | 0 | 249 | 258 | 53 | 0 | 249 | 258 | 246 | 0 | 250 | 258 | 249 | 0 | 169 | 0 | 159 | 251 | 124 | 0 | 0 | 0 | 0 | 0 |
| 1999 | 238 | 256 | 246 | 250 | 246 | 258 | 175 | 258 | 243 | 255 | 237 | 0 | 224 | 0 | 244 | 257 | 246 | 0 | 242 | 258 | 36 | 0 | 250 | 257 | 260 | 0 | 246 | 258 | 261 | 0 | 221 | 0 | 206 | 248 | 237 | 0 | 0 | 0 | 0 | 0 |
| 2000 | 237 | 253 | 251 | 257 | 244 | 258 | 240 | 236 | 237 | 257 | 217 | 0 | 206 | 0 | 245 | 254 | 245 | 0 | 244 | 258 | 168 | 0 | 253 | 257 | 260 | 0 | 246 | 258 | 260 | 0 | 217 | 0 | 207 | 252 | 246 | 0 | 36 | 0 | 0 | 0 |
| 2001 | 238 | 251 | 246 | 242 | 248 | 258 | 82 | 23 | 218 | 258 | 247 | 0 | 156 | 0 | 254 | 30 | 245 | 0 | 247 | 258 | 220 | 0 | 249 | 258 | 261 | 0 | 244 | 258 | 261 | 0 | 230 | 0 | 172 | 250 | 239 | 0 | 221 | 0 | 120 | 0 |
| 2002 | 243 | 249 | 245 | 249 | 247 | 258 | 35 | 256 | 222 | 258 | 249 | 220 | 211 | 222 | 257 | 0 | 246 | 230 | 249 | 258 | 227 | 0 | 252 | 255 | 261 | 230 | 250 | 258 | 261 | 0 | 201 | 0 | 173 | 251 | 238 | 0 | 189 | 0 | 252 | 0 |
| 2003 | 247 | 253 | 249 | 224 | 251 | 257 | 232 | 256 | 232 | 256 | 251 | 250 | 229 | 252 | 251 | 0 | 251 | 257 | 248 | 257 | 239 | 0 | 251 | 257 | 260 | 257 | 250 | 257 | 260 | 0 | 237 | 0 | 226 | 255 | 244 | 0 | 239 | 0 | 257 | 0 |
| 2004 | 253 | 257 | 256 | 235 | 260 | 259 | 259 | 259 | 243 | 259 | 255 | 253 | 253 | 254 | 257 | 0 | 261 | 259 | 260 | 259 | 243 | 195 | 248 | 259 | 261 | 259 | 260 | 259 | 260 | 197 | 199 | 185 | 248 | 254 | 249 | 196 | 253 | 197 | 255 | 192 |
| 2005 | 244 | 254 | 246 | 242 | 252 | 258 | 255 | 258 | 237 | 258 | 243 | 229 | 244 | 257 | 242 | 0 | 255 | 258 | 255 | 258 | 249 | 253 | 257 | 258 | 260 | 258 | 255 | 258 | 250 | 257 | 179 | 240 | 239 | 251 | 256 | 258 | 253 | 258 | 253 | 249 |
| 2006 | 249 | 253 | 250 | 252 | 253 | 257 | 252 | 257 | 246 | 256 | 249 | 249 | 250 | 253 | 250 | 0 | 253 | 257 | 253 | 257 | 248 | 252 | 253 | 257 | 254 | 257 | 253 | 257 | 246 | 251 | 201 | 234 | 246 | 255 | 251 | 256 | 252 | 257 | 245 | 249 |
| 2007 | 245 | 252 | 246 | 243 | 250 | 257 | 250 | 257 | 243 | 251 | 245 | 250 | 244 | 251 | 244 | 146 | 250 | 257 | 250 | 257 | 243 | 244 | 251 | 257 | 250 | 257 | 250 | 257 | 243 | 256 | 244 | 246 | 244 | 249 | 244 | 257 | 250 | 256 | 242 | 257 |
| 2008 | 245 | 257 | 247 | 247 | 255 | 259 | 255 | 259 | 244 | 258 | 245 | 243 | 245 | 250 | 247 | 244 | 255 | 259 | 255 | 259 | 241 | 258 | 255 | 259 | 255 | 259 | 255 | 259 | 244 | 258 | 244 | 258 | 245 | 243 | 242 | 258 | 255 | 259 | 243 | 259 |
| 2009 | 251 | 253 | 252 | 245 | 257 | 258 | 257 | 258 | 240 | 250 | 250 | 252 | 247 | 245 | 240 | 243 | 257 | 258 | 257 | 258 | 253 | 258 | 257 | 258 | 257 | 258 | 257 | 258 | 253 | 258 | 252 | 255 | 249 | 238 | 253 | 258 | 257 | 258 | 252 | 258 |
| 2010 | 68 | 251 | 71 | 239 | 73 | 259 | 73 | 259 | 71 | 242 | 71 | 249 | 68 | 241 | 68 | 248 | 73 | 259 | 73 | 259 | 73 | 259 | 73 | 259 | 73 | 259 | 73 | 259 | 73 | 259 | 73 | 253 | 73 | 246 | 73 | 259 | 73 | 259 | 74 | 259 |

Note: For each currency, the left column is for the daily data from AIG-FP and the right column is from WM/Reuters. AIG-FP has fewer observations for 2010 because the last observation of the AIG-FP data is for April 19, 2010.