Are Intermediary Constraints Priced?*

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Abstract

Violations of no-arbitrage conditions measure the shadow cost of constraints on intermediaries, and the risk that these constraints tighten is priced. We demonstrate in an intermediary-based asset pricing model that violations of no-arbitrage such as covered interest rate parity (CIP) violations, along with intermediary wealth returns, can be used to price assets. We describe a "forward CIP trading strategy" that bets on CIP violations becoming smaller, and show that its returns help identify the price of the risk that the shadow cost of intermediary constraints increases. This risk contributes substantially to the volatility of the stochastic discount factor, and appears to be priced consistently in U.S. treasury, emerging market sovereign bond, and foreign exchange portfolios.

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1 Introduction

Covered interest parity (CIP) violations have been interpreted by many authors as a sign that intermediaries are constrained (e.g. Du et al. (2018), Boyarchenko et al. (2018), Hébert (2018)). Meanwhile, the intermediary asset pricing literature has argued that constraints on intermediaries have important implications for the pricing of assets (see He and Krishnamurthy (2017) for a survey).

In this paper, we combine these two ideas, and provide a direct test of whether the risk that intermediary constraints become larger is priced. We begin by demonstrating, in a standard intermediary asset pricing model, that the intermediaries' stochastic discount factor (SDF) can be written as a function of the return on the manager of an intermediary's wealth and the magnitude of a cross-currency basis (i.e. a CIP violation). The existence of liquid foreign exchange (FX) and interest rate derivative across very granular maturities allows us to directly measure innovations to intermediaries' SDF due to shocks to the cross-currency basis. We argue that the most straightforward test of this model is a test of whether *"forward CIP trading strategies"* that bet on arbitrages becoming smaller earn excess returns.

We then proceed to the data, and estimate the excess returns of these forward CIP trading strategies. We define the forward CIP trading strategy to be using FX forwards and forward-starting interest rate swaps to conduct a forward-starting *CIP trade*, and then unwinding the trade at its forward starting date. Consider a trader who, at time t, enters into a forward-starting CIP trade to go long in Japanese yen and short U.S. dollars for three months between $t+1$ and $t+4$, with the currency risk fully hedged. We refer to this trade as a one-month forward three-month CIP trade. In a month, at $t+1$, the trader unwinds the forward CIP trade by going long in U.S. dollars and short Japanese yen for three months, exactly cancelling all the promised cash flows of the forward CIP trade. The profits of this forward CIP trading strategy are proportional to the difference between the market-implied one-month forward three-month CIP deviation observed at t and the actual three-month CIP deviation realized one month later at $t+1$. The forward

CIP trading strategy has a positive (negative) return if the future CIP deviation is smaller (bigger) than the market-implied forward CIP deviation today.

The expected return on the forward CIP trading strategy offers a direct test of intermediary asset pricing theories in which large CIP deviations indicate that intermediaries are very constrained, because the forward CIP trading strategy pays off poorly in these constrained states. If the constraints of financial intermediaries are indeed a priced factor, we should expect the forward CIP trading strategy to earn positive excess returns on average, as a risk premium to compensate investors for bearing the systematic risk exposure to variations in the shadow cost of intermediary constraints. At the same time, if intermediaries are not constrained, there will be no CIP violations, and our forward CIP trading strategy is unlikely to be profitable.

We find that there is a significant risk premium in our forward CIP trading strategy during the post-financial crisis period. Specifically, we study our forward CIP trading strategy for seven widely-traded foreign currencies vis-à-vis the US dollar: the Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), euro (EUR), British pound (GBP), New Zealand dollar (NZD), and Japanese yen (JPY). At the individual currency level, we generally find positive returns for high interest rate currencies and negative returns for low interest rate currencies. Moreover, the magnitude of the profits is significantly larger post-crisis than pre-crisis, consistent with the fact that CIP violations were very small before the recent financial crisis, became large during the crisis, and remained large after the crisis (Du et al. (2018)).

Guided by the literature on unhedged FX carry trade returns (such as Lustig et al. (2011) and Verdelhan (2018)), we also consider two trading strategies based on two portfolios of currencies. The "carry" strategy goes long in the forward CIP trading strategy of a high-interest-rate currency (AUD) vis-à-vis the dollar, and short in the forward CIP trading strategy of a low-interest-rate currency (JPY) vis-à-vis the US dollar. The "dollar" trading strategy goes long in the forward CIP trading strategy of all individual currencies vis-à-vis the US dollar with equal weights. We find statistically and economically significant Sharpe ratio equal to 1.4 for our carry strategy post-crisis. In contrast, we do not find evidence of risk premia when using the dollar strategy. We argue that this is consistent with the predictions of our model, which emphasizes the role of the cross-currency bases with the largest (in absolute value) magnitudes.

We also test our model's ability to price the cross section of assets, in an exercise building on the work of He et al. (2017) and Pasquariello (2014). Relative to the He et al. (2017) framework, our model adds the innovation to the carry-weighted cross-currency basis as a pricing factor. We find evidence that the price of this basis risk in US treasurys, FX portfolios, and sovereign bonds is close to the price we estimate using our forward CIP trading strategy. We also observe that while innovations to our basis factor are correlated with innovations to the He et al. (2017) intermediary factor, the two factors suggest different paths of intermediary marginal utility in recent years, and that the basis factor provides information not incorporated into the intermediary factor or captures similar information more precisely.

The addition of this basis factor improves the ability of the model to price the cross section of assets, a result that is reminiscent to the findings of Pasquariello (2014). However, the interpretation of our result is quite different. Our model argues that the CIP violations documented in the post-crisis period by Du et al. (2018) are caused by regulatory constraints, and that variation in the cost of these constraints as measured by CIP violations should be priced. In contrast, Pasquariello (2014) constructs a market dislocation index from a variety of currency-related arbitrages including CIP violations and triangular arbitrage (e.g. spot dollar-yen and dollar-euro vs. yen-euro), using data ending in 2009. During most of this period, all of these arbitrages were small, and many papers in the literature argued that they could be explained by transaction costs, stale prices, and related issues. The results of Pasquariello (2014) should be understood as demonstrating that times when transaction costs are high and markets are fast enough to create stale prices are also times of high marginal utility. This point is interesting in its own right, but conceptually distinct from our argument that the shadow cost of regulatory constraints for intermediaries is a priced risk factor.

Our paper sits at the intersection of literature on arbitrage and on intermediary asset pricing. Recent empirical work on covered interest parity violations (Du et al. (2018)) has documented the existence and time series properties of these arbitrages, as well as the quarter-end dynamics of these arbitrages arising from bank regulations. Boyarchenko et al. (2018) attribute the existence a broad class of arbitrages to non-risk-weighted leverage constraints due to bank regulations, and Hébert (2018) interprets these arbitrages through an optimal policy framework.

The existence of these regulations is one necessary ingredient for the existence of arbitrages, because the regulations prevent intermediaries from closing the arbitrage. A second necessary ingredient is some form of limited or constrained market access for other non-regulated agents in the economy. These two ingredients are also the key ingredients of intermediary asset pricing models (e.g. He and Krishnamurthy (2011)). A recent survey of intermediary asset pricing, He and Krishnamurthy (2017), summarizes this literature. Relative to the existing literature, our model emphasizes literal arbitrages, as opposed to the intermediaries' ability to access investments with favorable risk/return trade-offs. In this respect, our model builds on Garleanu and Pedersen (2011). We also contribute to this literature by emphasizing the importance of intertemporal hedging considerations, following Campbell (1993), whereas much of the literature (e.g. He and Krishnamurthy (2011), Garleanu and Pedersen (2011), and He et al. (2017)) relies on log utility for intermediaries and neglect these considerations. In taking the model to the data, we are building on the work of He et al. (2017), Adrian et al. (2014), and Haddad and Muir (2017).

We begin by introducing our model in section 2. We then describe our forward CIP trading strategy and the relevant data in section 3. Section 4 presents our main results on excess returns and high Sharpe ratios for these strategies. Section 5 tests our model in the cross section of asset prices. We conclude in section 6.

2 Hypothesis and Model

In our empirical analysis that follows, we will test the hypothesis that changes in the magnitude of cross-currency bases (i.e. CIP violations) are a priced risk factor. In particular, we are motivated by log SDFs m_{t+1} of the form

$$m_{t+1} = \mu_t + \gamma r^w_{t+1} + \xi |x_{t+1,1}|, \tag{1}$$

where r^w_{t+1} is the return on the manager of an intermediary's wealth portfolio and $|x_{t+1,1}|$ is the absolute value of a one-period cross currency basis. Our hypothesis, in the context of this functional form, is that ξ is economically and statistically distinguishable from zero.

The most direct test of this hypothesis is to study a derivative contract whose payoff is linear in $|x_{t+1,1}|$. If such a contract has an excess return that cannot be explained by the covariance between $|x_{t+1,1}|$ and the other parts of the hypothesized SDF (i.e. r^w_{t+1}), we should conclude that innovations in the cross-currency basis are indeed a priced risk factor (or at least correlated with an omitted factor). The forward CIP trading strategy that we construct in our empirical analysis is exactly this derivative contract.

Our hypothesis is motivated by an intermediary asset pricing model, which we describe below. The purpose of the model is both to motivate the hypothesis and to provide a framework to interpret our results. The model is a discrete time version of He and Krishnamurthy (2011) that incorporates a regulatory constraint (building on He and Krishnamurthy (2017)). We derive the particular functional form of equation (1) from intertemporal hedging considerations, following Campbell (1993), under the assumptions of joint log-normality and homoskedasticity.

The basic intuition of the model is as follows. Arbitrages like a cross-currency basis arise due to a regulatory constraint, and therefore provide a way to measure the multiplier associated with that constraint (a point emphasized by Hébert (2018)). For any asset or portfolio affected by the constraint, and in particular the portfolio of the intermediary's assets, a binding multiplier implies an excess return relative to the intermediary's SDF (otherwise, the constraint wouldn't bind). Consequently, the magnitude of future arbitrage opportunities predicts future returns for the intermediary's portfolio. Intertemporal hedging considerations that arise from CRRA preferences with relative risk aversion $\gamma > 1$ imply that any predictor of future arbitrage opportunities, and hence future portfolio returns, co-varies with the SDF. Therefore, if innovations to a cross-currency basis are persistent (and we find in data that they are), we should expect those innovations to co-vary with the SDF.

The remainder of this section outlines the model and each of the steps in the preceding argument. We provide a full description of the model in the appendix, section C. Readers willing to grant our hypothesis as inherently interesting are invited to skip to the next section.

Our model adopts the perspective of He and Krishnamurthy (2011) and the subsequent intermediary asset pricing literature (surveyed in He et al. (2017)), and in particular the notion that the manager of the intermediary is an agent whose SDF should price assets. The model is a discrete time version of He and Krishnamurthy (2011), and is partial equilibrium in that we only consider the problem facing the manager of the intermediary. We add to He and Krishnamurthy (2011) a variety of assets, including both "cash" assets and derivatives, and a regulatory constraint. We study a manager with CRRA preferences over consumption (rather than focus on log preferences), because these preferences will allow us to discuss the role that intertemporal hedging concerns play in the model.

In our model, the manager of an intermediary raises equity and debt financing from outside investors each period. However, a moral hazard constraint requires that the manager retain at least a share $(1+\psi)^{-1}$ of the risk of the intermediary. Moreover, a regulatory constraint (for example, a leverage ratio requirement) requires that the intermediary finance a certain fraction of its assets with equity, as opposed to debt. Let $i \in I$ denote an asset that the intermediary can hold, let α_t^i be the intermediary's holding of asset i at time t as a share of the intermediary's equity, N_t. Following He et al. (2017), we write the regulatory constraint as

$$\sum_{i \in I} k^i |\alpha_t^i| \leq 1 \tag{2}$$

This constraint captures some of the key features of leverage ratios and risk-weighted capital requirements. First, to the extent that the k^i differ across assets, the constraint can capture risk-weights. Second, the constraint is relaxed by increasing the level of equity financing the intermediary relative to debt, holding fixed the dollar holdings of each asset. Third, the constraint can omit certain assets, such as derivatives, entirely, consistent with how some but not all leverage constraints and risk-weighted capital constraints operate. In our analysis, for clarity of exposition, we will assume that derivatives are not included in the regulatory constraint.

Equity in the intermediary can come from two sources, the bank manager and households. Let N_t^M denote the equity contribution of the manager, and with the remainder of the intermediary's equity, $N_t - N_t^M$, coming from households.

Let ϕ_t denote the share of the intermediary assets that will be paid to the manager, with $1 - \phi_t$ going to the households. In He and Krishnamurthy (2011), which is a continuous time model, the manager is paid a fee, and invests all of the wealth she does not consume in the equity of the intermediary. In our discrete time version of the model, these results imply that the manager is paid in equity, meaning that the share the manager receives (ϕ_t) is not the same as the share she contributes (N_t^M/N_t). These results also imply that the manager's contribution to the intermediary is $N_t^M = W_t^M - C_t^M$, where W_t^M is the manager's wealth at the beginning of the period and C_t^M is her consumption.

We define the ratio of what the share the manager receives to the share she contributes as

$$f_t^M \equiv \frac{\phi_t N_t}{N_t^M} \geq 1,$$

and will refer to this ratio as the manager's fee. We discuss how this fee is determined in Appendix Section C. Note that this ratio is also the gross return for the manager on the wealth she contributes, if the intermediary's assets have zero net return.

The manager's wealth next period, W_{t+1}^M will depend on both this fee income and the returns of the intermediary, which in turn depends on the asset allocation α_t^i. The manager receives

$$W_{t+1}^M = (W_t^M - C_t^M) f_t^M (R_t^b + \sum_{i \in I} \alpha_t^i (R_{t+1}^i - R_t^b)), \tag{3}$$

where R_t^b is the gross interest rate paid on the intermediary's risk-free debt[1] and R_{t+1}^i is the gross return on asset i from time t to time $t+1$.[2]

The manager chooses the intermediary's asset allocation freely (that is, she does not commit to any particular asset allocation when raising funds from the households). Because of this assumption, the equilibrium fee f_t^M depends only on the investment opportunities of the intermediary, and is exogenous from the perspective of the manager. Let z_t denote the vector of state variables that describes the distribution of the available returns.

The manager's problem, given wealth W_t^M and state variable z_t, is to maximize her utility from consumption and continuation value, as in a standard consumption-savings problem. That is,

$$V(W_t^M, z_t) = \max_{\{\alpha_t^i\}_{i\in I}, C_t^M} \frac{(C_t^M)^{(1-\gamma)}}{1-\gamma} + \beta E[V(W_{t+1}^M, z_{t+1})|z_t] \tag{4}$$

subject to the equation defining continuation wealth (3) and the regulatory constraint (2).

The manager solves a standard consumption-savings problem, with two twists. First, she receives exogenous fee income in proportion to her wealth, which effectively increases her return on her wealth portfolio. Second, she faces a regulatory constraint on her portfolio choice. To relate the manager's problem to standard portfolio-choice results, we define the log return on the manager's wealth portfolio as

$$r_{t+1}^w = \ln f_t^M + \ln(R_t^b + \sum_{i\in I} \alpha_t^i (R_{t+1}^i - R_t^b))$$

We also define consumption growth as $\Delta c_{t+1}^M = \ln C_{t+1}^M - \ln C_t^M$.

With these definitions, the Euler equation associated with the wealth portfolio is the standard one,

$$1 = E[\exp(r_{t+1}^w - \gamma \Delta c_{t+1}^M)|z_t]. \tag{5}$$

The first-order condition associated with the portfolio share α_t^i is

$$E[exp(-\gamma \Delta c_{t+1}^M)(R_{t+1}^i - R_t^b)|z_t] = \lambda_t^{RC} k^i sgn(\alpha_t^i), \tag{6}$$

[1] One disadvantage of using discrete time instead of continuous time (as in He and Krishnamurthy (2011)) is that default is possible. We completely ignore this issue.

[2] To accommodate derivatives in this expression, we define the gross return on a derivative as the sum of the profits of the derivative and R_t^b.

where $sgn(\cdot)$ is the sign function and λ_t^{RC} is the (scaled) multiplier on the regulatory constraint.[3]

Armed with these first-order conditions, we are now in a position to described how arbitrages such as a cross-currency basis can exist in the model, and how they are related to other asset prices. Consider an asset consisting of a foreign currency bond, with a foreign currency risk-free rate R_t^c, combined with spot and forward currency trades to convert the return into dollars. This asset is a synthetic risk-free dollar asset; in the presence of a cross-currency basis, it may have a different interest rate than the intermediary's borrowing rate R_t^b.

Let S_t denote the exchange rate at time t (in units of foreign currency per U.S. dollar), and let $F_{t,1}$ denote the one-period ahead forward exchange rate. We define the spot one-period cross-currency basis as

$$X_{t,1} = \frac{R_t^b}{R_t^c} \frac{F_{t,1}}{S_t} - 1$$

and let $x_{t,1} = \ln(1 + X_{t,1})$ be the log version.

Using the first-order conditions for the foreign bond and the exchange rate forward, we find that

$$E[\exp(-\gamma \Delta c_{t+1}^M)|z_t] R_t^b (1 - \exp(-x_{t,1})) = -\lambda_t^{RC} k^c sgn(\alpha_t^c), \tag{7}$$

where k^c and α_t^c are the risk-weights and portfolio shares of the foreign currency risk-free bond, recalling we have assumed derivatives do not enter the regulatory constraint.[4]

This equation offers several immediate implications. First, if there is an arbitrage available, the regulatory constraint must bind– otherwise, the intermediary would take advantage of the arbitrage. Second, the intermediary will trade the foreign currency risk-free asset in the direction that takes advantage of the cross-currency basis (long if $X_{t,1} < 0$, short if $X_{t,1} > 0$). Third, and most important for our purposes, we can take the absolute value of both sides of equation 7 and solve explicitly for the multiplier on the regulatory constraint. Plugging this back into the first-order condition for an arbitrary

[3]In the particular case in which $\alpha_t^i = 0$, we have the usual inaction inequalities, $-\lambda_t^{RC} k^i \leq E[exp(-\gamma \Delta c_{t+1}^M)(R_{t+1}^i - R_t^b)|z_t] \leq \lambda_t^{RC} k^i$.

[4]Considering regulatory constraints that include derivatives complicates the analysis but does not alter the main predictions of the model that we will take to the data.

asset i, we find that

$$E[exp(-\gamma\Delta c^M_{t+1})(R^i_{t+1} - R^b_t(1 + \frac{k^i}{k^c}sgn(\alpha^i_t)|1 - \exp(-x_{t,1})|)|z_t] = 0. \quad (8)$$

This first-order condition shows that the manager acts as if she faced a different risk-free rate for each asset, one that was higher than her borrowing rate for assets the intermediary is long and lower for assets the intermediary is short.

One implication of this first-order condition is that, holding risk premia constant, the absolute value of the cross-currency basis should predict asset returns, at least for those assets the intermediary is consistently long or short. To see this more clearly, we will suppose that the asset returns R^i_t and consumption C^M_t are jointly log-normal, and that all conditional variances and covariances are constant (i.e. that the model is homoskedastic). Under these assumptions, and using the first-order approximation

$$\ln{(1 + \frac{k^i}{k^c}sgn(\alpha^i_t)|1 - \exp(-x_{t,1})|)} \approx \frac{k^i}{k^c}sgn(\alpha^i_t)|x_{t,1}|,$$

we have

$$E[r^i_{t+1}|z_t] - r^b_t + \frac{1}{2}(\sigma^i)^2 = \gamma\sigma^{ic} + \frac{k^i}{k^c}sgn(\alpha^i_t)|x_{t,1}|, \quad (9)$$

where $r^i_{t+1} = \ln R^i_{t+1}$, $r^b_t = \ln R^b_t$, $(\sigma^i)^2$ is the conditional variance of the log return, and σ^{ic} is the conditional covariance of the log return and log consumption growth. Compared to the textbook formula (Campbell (2017)), the expected excess return now includes an effect of the cross-currency basis, scaled by the relative risk-weights between asset i and the foreign-currency bond. This result is essentially the "margin-based CCAPM" result of Garleanu and Pedersen (2011), except that we have used a cross-currency basis to measure that shadow value of the constraint.

This leads to our first conjecture: that the magnitude of the cross-currency basis should predict excess returns on assets that are consistently held by intermediaries. We should emphasize, however, that the "holding risk premia" constant caveat is potentially quite important. It may very well be the case that the cross-currency basis co-moves with other variables in z_t that predict changing variances and co-variances, and hence risk premia and expected returns.

We should also emphasize that this conjecture is difficult to test. Return predictability regressions often require long time series, but our theory only applies to the period in which regulatory constraints create CIP violations (essentially the post-financial-crisis period). It may be possible to construct stronger tests even in short data samples by imposing structure on the coefficients k^i/k^c, by taking a stand on the nature of the regulatory constraint. For example, a pure leverage constraint might set all of these coefficients to unity for all assets i.

We take an alternative approach, by emphasizing a second prediction of the model. Because the cross-currency basis predicts returns for all assets i, it predicts returns on the manager's wealth portfolio. The work of Campbell (1993) demonstrates that, away from log utility, covariance with expected future wealth portfolio returns is priced. Consequently, by departing from the log utility assumption of He and Krishnamurthy (2011), Garleanu and Pedersen (2011),[5] and He et al. (2017), we arrive at our second prediction: covariance with the cross-currency basis is priced.

To derive this result, we specialize equation (9) to the wealth portfolio, recalling that the wealth portfolio also receives an extra return from the fee income:

$$E[r^w_{t+1}|z_t] - r^b_t + \frac{1}{2}(\sigma^w)^2 = \gamma\sigma^{wc} + \frac{1}{k^c}|x_{t,1}| + \ln f^M_t. \quad (10)$$

Note that, by definition, the intermediary is long its own portfolio, so the sign term has disappeared, and the sum of the risk weights and portfolio shares always equals one, so $k^w = 1$.

We next combine the log-linear approximation of the intertemporal budget constraint developed by Campbell (1993) and the Euler equation for the wealth portfolio (equation 5). These two equations together show that

$$\Delta c^M_{t+1} - E[\Delta c^M_{t+1}|z_t] = r^w_{t+1} - E[r^w_{t+1}|z_t] + (1-\gamma^{-1})\sum_{j=1}^{\infty}\rho^j(E[r^w_{t+1+j}|z_{t+1}] - E[r^w_{t+1+j}|z_t]).$$

Note that this formula is identical to a result in Campbell (1993), because the Euler equation for the wealth portfolio ((equation 5)) is not distorted by the regulatory constraint.

Plugging our equation for the expected return on the wealth portfolio (10) into this equation, and then the resulting expression for consumption growth into the equation defining the return of an arbitrary asset i (equation (9)), leads to our main result.

[5] Garleanu and Pedersen (2011) use log utility for their "brave" agents, who are the "intermediaries" of the model.

Theorem 1. *The expected arithmetic excess return of an arbitrary asset i can be written as*

$$E[r^i_{t+1}|z_t] - r^b_t + \frac{1}{2}(\sigma^i)^2 = \gamma\sigma^{iw} + (\gamma-1)\sigma^{ih} + \frac{k^i}{k^c} sgn(\alpha^i_t)|x_{t,1}|, \tag{11}$$

where σ^{iw} is the conditional covariance with the wealth portfolio and

$$\sigma^{ih} = Cov[r^i_{t+1}, \sum_{j=1}^{\infty} \rho^j (E[\cdot|z_{t+1}] - E[\cdot|z_t])(\frac{1}{k^c}|x_{t+j,1}| + \ln f^M_{t+j} + r^b_{t+j})|z_t]. \tag{12}$$

Recall that under our homoskedasticity assumption these covariances are constant over time.

This theorem implies that, if $\gamma > 1$, the manager will be concerned about hedging her investment opportunities, and will demand a risk premium for assets whose returns co-vary with those investment opportunities. Future arbitrage opportunities are a particularly stark example of an investment opportunity, and indicative of the expected returns on the wealth portfolio, and hence returns that co-vary with future arbitrages should have a high risk premium.

The last piece of our argument is the conjecture (which is verified in the data) that arbitrage opportunities are likely to be persistent. As a result, shocks to the cross-currency basis at time $t+1$ are likely to be indicative of shocks to the arbitrage at later dates. For illustrative purposes only (and ignoring issues about negative numbers), suppose that $|x_{t,1}|$ follows an AR(1) process,

$$|x_{t+1,1}| = \bar{x} + \phi|x_{t,1}| + \sigma^{|x|}\epsilon_{t+1},$$

where ϵ_{t+1} is an I.I.D. standard normal shock. In this case, we have

$$\sum_{j=1}^{\infty} \rho^j (E[\cdot|z_{t+1}] - E[\cdot|z_t])\frac{1}{k_c}|x_{t+j,1}|) = \frac{1}{k_c}\frac{1}{1-\rho\phi}\sigma^{|x|}\epsilon_{t+1}.$$

Under very strong assumptions (i.e. that borrowing rates r^b_{t+j} and fees f^m_{t+j} are uncorrelated with ϵ_{t+1}), the constant $\frac{1}{k_c}\frac{1}{1-\rho\phi}\sigma^{|x|}$ is equal to the value of ξ defined in our hypothesized functional form for the log SDF. More generally, projecting the revisions in expectations found in equation (12) onto the current innovation in the cross-currency basis, under the assumption that such innovations are persistent, motivates our hypothesized functional form for the log SDF, equation (1).

This description should also make it clear that our simple functional form likely omits important elements of the SDF. Any other variable that predicts these revisions in expectations should also enter the SDF. Moreover, the innovation of the cross-currency basis might enter the SDF not only because it predicts future cross-currency bases, but also because it predicts future borrowing rates or fees (or, in a heteroskedastic model like Campbell et al. (2018), future volatilities).

Note also that our description of the model has emphasized a single cross-currency basis, whereas our empirical analysis will consider a variety of currencies and portfolios of currencies. In the context of the model, heterogeneity in the magnitude of the cross-currency basis across currencies can arise only due to different k^i for bonds in different currencies, or if the manager has zero portfolio weight on all arbitrages except the one with the largest magnitude. In other words, why would an intermediary conduct a USD-EUR arbitrage if a USD-JPY arbitrage offers larger profits? Our model, and in particular the regulatory constraint, is too simplified to offer much guidance on this issue. That said, the model does push us in our empirical work to focus on the cross-currency bases with the largest CIP violations.

Our model also demonstrates that the shadow cost of regulatory constraints can be measured with CIP violations, but is silent on why CIP violations and investment opportunities more generally vary over time. We expect that in a general equilibrium setting, both supply shocks (low intermediary net worth) and demand shocks (changing household preferences across currencies) will determine the shadow cost of the constraints on intermediaries. If our model allowed for changes in the structure of the regulatory constraint, these changes would also create variation in the shadow cost. Our results should be understood as demonstrating that, regardless of what is driving changes in these shadow costs, a stochastic discount factor that incorporates intermediary wealth and CIP violations should be able to price the assets available to the intermediary.

Lastly, a word on magnitudes. Innovations in CIP violations are small ($\sigma^{|x|}$ is on the order of basis points). However, intermediaries are quite levered, meaning that k^c might be less than ten percent, consumption-wealth ratios for managers are likely small (meaning ρ is close to one), and innovations in CIP violations are very persistent (ϕ is close to one). Consequently, a significant fraction of the volatility of our hypothesized SDF might be attributable to innovations in CIP violations as opposed to returns on the manager's wealth portfolio.

In this section, we have outlined a model that motivates our hypothesis that innovations in the magnitude of CIP violations are a priced risk factor. As discussed above, the most direct way of testing this hypothesis is to look for excess returns on derivatives that bet on whether the magnitude of a CIP violation will increase or decrease. In the next section, we describe the forward CIP trading strategy, which is exactly this kind of bet, and discuss how we construct the profits from the strategy using the available financial market data.

3 Forward CIP Arbitrage

We study the forward CIP trading strategy in three steps. First, we revisit "spot" cross-currency bases (as described in recent data by Du et al. (2018)), and describe the cross-currency bases based on overnight index swap (OIS) rates that we will use in our main empirical analysis. Second, we discuss "forward" cross-currency bases, constructed from forward-starting OIS and FX forwards. Third, we introduce our forward CIP trading strategy, which initiates a forward-starting cross-currency basis trade but then unwinds the trade once it becomes a spot cross-currency basis trade. We emphasize that this trading strategy is not itself an arbitrage, but rather a bet on whether available arbitrages will become bigger or smaller. For robustness, we also consider a forward CIP trading strategy based on interbank offer rates (IBOR) and forward rate agreements (FRAs) indexed to these IBOR rates.

We study cross-currency bases in seven major currencies, using the US dollar as the base currency: AUD, CAD, CHF, EUR, GBP, JPY and NZD.[6] Our preferred specification involves portfolios of the forward CIP trading strategies using these currencies, in particular a "dollar" portfolio and a "carry" portfolio, whose construction we detail

[6]We began with the G10 currencies, and excluded the Norwegian Krona (NOK) and Swedish Krona (SEK) due to limited data availability on OIS rates and IBOR FRAs.

below.

All data on the spot and forward foreign exchange rates, interest rate swaps and FRAs are daily data obtained from Bloomberg using London closing rates for the currencies we study. Our dataset begins in January 2003 and ends in August 2018. We divide our data into three periods: Pre-Crisis, January 1, 2003 to June 30, 2007, Crisis, July 1, 2007 to June 30, 2010, and Post-Crisis, July 1, 2010 to August 30, 2018. The OIS and FRA data for the pre-crisis period appears less reliable (more missing or erroneous values) than the data over the crisis and post-crisis periods.

3.1 OIS-Based Spot Cross-Currency Bases

Let $R^c_{t,0,\tau}$ denote the annualized spot gross τ-month interest rate in foreign currency c available at time t, and let $R^\$_{t,0,\tau}$ denote the corresponding spot rate in U.S. dollars. Throughout the paper, the middle subscript "0" denotes a spot rate. We adopt the convention that exchange rates are expressed in units of foreign currency per U.S. dollar. That is, an increase in the spot exchange rate at time t, S_t, denotes a depreciation of the foreign currency and an appreciation of the U.S. dollar. The τ-month forward exchange rate at time t is $F_{t,\tau}$.

Following convention of the literature (e.g. Du et al. (2018)), we define the τ-month spot cross-currency basis at time t as

$$X^c_{t,0,\tau} = \frac{R^\$_{t,0,\tau}}{R^c_{t,0,\tau}} \left(\frac{F_{t,\tau}}{S_t}\right)^{\frac{12}{\tau}} - 1,$$

and the log version as

$$x^c_{t,0,\tau} = \ln\left(1 + X^c_{t,0,\tau}\right).$$

Note that these definitions are identical to the ones employed in our model, except that we now consider an arbitrary horizon τ and use annualized interest rates.

The classic covered interest parity condition is that $x^c_{t,0,\tau} = X^c_{t,0,\tau} = 0$. If the cross-currency basis $x^c_{t,0,\tau}$ is positive, then the direct U.S. dollar interest rate, $R^\$_{t,0,\tau}$, is higher than the synthetic dollar interest rate constructed from the foreign currency bond and exchange rate transactions. If it is negative, the reverse is true.

The CIP condition is a textbook no-arbitrage condition if the U.S. and foreign interest rates used in the analysis are risk-free interest rates. For our main analysis, we choose the OIS rate as our proxy for risk-free interest rate for our analysis. The OIS is an interest rate swap in which a fixed rate of interest is exchanged for a floating rate indexed to the overnight unsecured rate.[7]

The OIS is a good proxy for the risk-free rate across maturities for several reasons. First, the OIS allows investors to lock in fixed borrowing and lending rates for a fixed maturity, by borrowing and lending at the nearly risk-free floating overnight rate each day over the duration of the contract. Second, the interest rate swaps themselves have very little counterparty risk, because there are no exchanges of principal, only exchanges of interest. These derivative contracts are also highly collateralized and in recently years have been centrally cleared in most major jurisdictions. Third, OIS swaps are generally very liquid and traded at a large range of granular maturities (unlike repo contracts where liquidity is concentrated only at very short maturities).

Figure 1 shows the three-month OIS-based cross-currency basis for the seven sample currencies between January 2003 and August 2018. The three-month OIS basis was very close to zero before the crisis. During the peak of the GFC, the OIS basis was deeply negative for all currencies. After the GFC, OIS-based CIP deviations persisted. Among the seven sample currencies, the AUD and NZD have the most positive cross-currency basis, and the JPY, CHF, and EUR have the most negative cross-currency basis. Appendix Figure A1 shows three-month IBOR-based cross-currency bases, which follow similar patterns.

3.2 Forward Bases

We next define a forward-starting cross-currency basis. Trading a forward starting cross-currency basis allows an agent to lock-in the price of a cross-currency basis trade that

[7]The list of overnight reference rates for the OIS and their day count conventions for the seven major currencies currencies we study and the U.S. dollar can be found in Appendix Table A1. For three currencies, the OIS rate is non-standard. For CAD, the overnight rate is a repo rate; for NZD, the overnight rate is an administered central bank policy rate, which is not based on actual overnight transacitons; for CHF the unsecured overnight rate had volumes so low that the OIS rate was changed to reference a secured rate in 2017.

will start in the future.

We define a forward-starting cross-currency basis using forward interest rates and FX forwards. Let $R^c_{t,h,\tau}$ be the h-month forward-starting annualized τ-month gross interest rate in currency c at time t, and let $R^\$_{t,h,\tau}$ be the equivalent rate in US dollars. The forward-starting cross-currency basis is

$$X^c_{t,h,\tau} = \frac{R^\$_{t,h,\tau}}{R^c_{t,h,\tau}} \left(\frac{F_{t,h+\tau}}{F_{t,h}}\right)^{\frac{12}{\tau}} - 1, \tag{13}$$

and the log version is $x^c_{t,h,\tau} = \ln(1 + X^c_{t,h,\tau})$. Figure 2 illustrates the definition of the three-month spot basis and the one-month-forward three-month basis.

Equivalently, we can define the log h-month forward τ-month cross currency basis at time t in terms of spot cross-currency bases only under the assumption of no-arbitrage between forward interest rate swaps and the term structure of spot interest rate swaps:

$$x^c_{t,h,\tau} = \frac{h+\tau}{\tau} x_{t,0,h+\tau} - \frac{h}{\tau} x_{t,0,h}. \tag{14}$$

The equivalence between equations (13) and (14) is shown in Appendix A. From this equation (14), we observe that there is a close analogy between the forward cross-currency basis and the forward interest rate.

We next consider the typical shape of the term structure of CIP violations – that is, the shape of the cross-currency basis forward curve. Many different forward CIP trades are possible, as both the forward-starting horizon h and the tenor τ can vary. When selecting the forward CIP trades to include on the forward curve, we balance the desire to exhibit as many different forward-starting horizons as possible with the limitation that the most liquid and reliable OIS tenors are 1M, 2M, 3M, 4M, 6M, 9M, and 12M.

In Figure 3, we present the forward curves of AUD and JPY for all reliable horizons: 1M, 2M, 3M, 4M, 6M, and 9M. The tenor τ of these forward CIP trades differs, beginning at one month and increasing to three months. An alternative version of the forward curve that uses only three month tenors is presented in Figure A2.

We present these forward cross-currency bases as time series averages and for two currencies, AUD and JPY. These two currencies stand out in the data as they generally have among the most positive/negative spot cross-currency bases on average during our post-crisis sample period. For each currency, we divide our sample into three sub-samples based on the tercile of the level of the spot cross-currency basis. We then compute the time-series average of the spot and forward-starting cross-currency basis within each subsample.

From these forward curves, it is immediately apparent that the forward cross-currency bases tend to be larger than the spot cross-currency basis for AUD, and smaller for JPY. This fact is somewhat analogous to the tendency of the term-structure of interest rates to be upward sloping. If we think of forward cross-currency bases as being equal to expectations under a risk-neutral measure (an approach that is valid in our model despite the presence of arbitrage), then this suggests that the absolute value of spot cross-currency basis is generally expected to increase under the risk-neutral measure.

This raises the question of whether the spot cross-currency basis is expected to increase in absolute value under the physical measure. In other words, does the forward CIP trading strategy, which we define next, earns a positive risk premium?

3.3 Forward CIP Trading Strategy

A forward CIP trading strategy consists of a forward cross-currency basis trade and a spot cross-currency basis trade at a later date. At time t, an agent enters into the h-month forward τ-month cross-currency basis trade. After h months, the agent unwinds the trade by shorting the then-spot τ-month cross-currency basis.

Although the forward CIP trading strategy involves two potential arbitrage opportunities, it is itself risky in that the spot τ-month cross currency basis at time $t+h$ is not guaranteed to be equal to the h-month forward τ-month cross-currency basis at time t. Figure 4 illustrates the mechanics of a one-month-forward three-month forward CIP trading strategy.

The profits of this trading strategy are mainly a function of the realized cross-currency basis at time $t+h$ compared to τ-month forward cross-currency basis at time t. To first-order, the monthly profit per dollar notional (which can be thought of as an excess return) is

$$\pi^c_{t+h,h,\tau} \approx \frac{\tau}{12}(x^c_{t,h,\tau} - x^c_{t+h,0,\tau}).$$

We derive this expression, which is a first-order approximation, from a more exact calculation in the appendix, section B. The exact expression is complicated due to discounting effects, which are not straightforward in the presence of arbitrage opportunities. The term $\frac{\tau}{12}$ plays the role of a duration, converting the difference between the forward and realized basis, $x^c_{t,h,\tau} - x^c_{t+h,0,\tau}$, into a dollar profit per unit notional.

The key property of the forward CIP trading strategy for our purposes is that it allows an intermediary to bet on whether the cross-currency basis will be higher or lower than implied by the forward cross-currency basis. Our model equates the magnitude of the cross-currency basis with the degree to which regulatory constraints binds. Consequently, this strategy allows intermediaries to bet on whether constraints will be tighter or looser in the future.

Note that our forward CIP trading strategy is a valid trading strategy even if the underlying cross-currency basis is not actually tradable or not an arbitrage. For example, the NZD overnight index rate is not a market rate but rather an administered central bank policy rate. Despite this issue, the forward CIP trading strategy for NZD OIS is a valid trading strategy that bets on whether the basis as measured by OIS swaps referencing this rate becomes larger or smaller. Similarly, IBOR bases are not arbitrages if IBOR rates contain credit risk, but the IBOR-based forward CIP trading strategy is a feasible way of betting on whether the IBOR basis becomes larger or smaller.

Furthermore, the forward trading strategy per se does not materially contribute to the balance sheet constraints of financial intermediaries, especially in comparison with the spot CIP arbitrage. This is because interest rate forwards and FX derivatives have zero value at inception. The required initial and variation margins for the derivative positions are generally a few percent of the total notional of the trade. In contrast, the spot CIP arbitrage requires actual cash market borrowing and lending, which is very balance sheet intensive.

We also note that we do not have the data on transactions costs that would be required to implement our forward CIP trading strategy. Large intermediaries are likely to implement the strategy at low costs (either collecting the bid-offer when trading with clients or trading at close to the mid-price in inter-dealer transactions). Anecdotal evidence suggests that some hedge funds use interest rate and FX derivatives to arbitrage the term structure of CIP violations, suggesting that the transaction costs are not prohibitively large. However, it may well be the case that a typical trader in a small hedge fund paying the bid-offer on the various instruments used to implement the trading strategy would not find it profitable. We study these trading strategies because they reveal interesting information about intermediaries, and not because we advocate them as an investment strategy.

3.4 Cross-Currency Basis Portfolios

In our empirical analysis, we will focus primarily on two portfolios of cross-currency bases, "classic carry" and "dollar," rather than the cross-currency basis for a single currency relative to the dollar. Our portfolio construction builds on the literature on FX carry trade returns. The classic FX carry trade strategy goes long in the AUD and shorts the JPY, without hedging currency risk. Analogously, we define the classic carry strategy for the forward CIP trading strategy to be going long in the forward cross-currency basis for the AUD vis-à-vis the JPY, and short the later realized spot corss-currency basis for the same currency pair.[8] The monthly profit per dollar notional on the classical carry forward CIP trading strategy is then given by

$$\pi^{Carry}_{t+h,h,\tau} = \frac{\tau}{12}[(x^{AUD}_{t,h,\tau} - x^{JPY}_{t,h,\tau}) - (x^{AUD}_{t+h,0,\tau} - x^{JPY}_{t+h,0,\tau})]. \tag{15}$$

In addition, we examine the performance of a dollar forward CIP strategy that places equal weights on forward CIP trading strategy of individual sample currencies vis-à-vis the US dollar. The profit per dollar notional on the dollar forward CIP trading strategy is given by

$$\pi^{Dollar}_{t+h,h,\tau} = \frac{\tau}{12N}\sum_{i}^{N}(x^{i}_{t,h,\tau} - x^{i}_{t+h,0,\tau}). \tag{16}$$

In our main text, we study the profits from the 1M-forward CIP trading strategy in

[8] Equivalently, the strategy goes long in the forward CIP trade strategy for the AUD vis-à-vis the USD, and short in the forward CIP trade strategy for the JPY vis-à-vis the USD. The USD legs are canceled and thus the strategy is dollar-neutral.

individual currencies and these two portfolios. In Appendix Section E we present results using alternative methods of constructing carry and dollar portfolios.

4 Forward CIP Trading Strategy's Excess Returns

In this section, we present evidence that the forward CIP trading strategy earns excess returns on average. Our model interprets this fact as reflecting a concern for intertemporal hedging: changes in investment opportunities, as measured by cross-currency bases, are persistent and priced. We begin by presenting evidence that our forward CIP trading strategy is profitable. We then show that the excess returns associated with our trading strategy are predictable using the slope of the term structure of cross-currency basis, in a manner similar to the term structure return predictability regressions of Campbell and Shiller (1991).

4.1 Individual Currencies

We begin by discussing results for individual currencies. Panel A of Table 1 reports the profits per dollar notional on a forward CIP trading strategy in each of the seven sample currencies, for the one-month-forward three-month forward CIP trading strategy.[9] For each forward CIP trading strategy, we present the annualized mean profit per dollar notional and the Sharpe ratio by periods. Mean and Sharpe ratios are calculated using monthly profit per dollar notional and then scaled up by 12 and $\sqrt{12}$, respectively. Standard errors of the statistics are reported in brackets. We use the Newey-West standard errors based on the Newey-West HAC kernel with the Newey and West (1994) bandwidth selection procedure to account for overlapping returns.

Beginning with the pre-crisis period, we observe that for all currencies except NZD,[10] the pre-crisis profits are virtually zero. In contrast, post-crisis, the profits in most cur-

[9]Appendix Tables A2, A3, and A4 report the analogous results for three-month forward three-month arbitrage, and for IBOR-based arbitrages.

[10]Recall that the NZD ois swaps do not reference a tradable rate, and hence NZD might be expected to behave differently than the other bases.

rencies are larger in absolute value. Moreover, there is a distinct pattern in the sign of the profits. Low interest rate "funding currencies," like JPY, CHF, and EUR, have negative profits from the forward CIP trading strategy on average, whereas higher interest rate currencies like AUD have positive profits from the forward CIP trading strategy on average. In addition, CAD and GBP, currencies that have interest rates lower than AUD/NZD but higher interest rates than the other currencies, have strongly positive profits from the forward CIP trading strategy.

We also calculate the Sharpe ratios of the forward CIP trading strategy.[11] Pre-crisis, some currencies such as JPY have marginally statistically significant Sharpe ratios, but this reflects small mean profits and even smaller standard deviations. In contrast, post-crisis, four currencies have non-trivial mean profits and substantial Sharpe ratios. Mean profits and Sharpe ratios from the crisis period are noisily estimated, as one might expect.

Broadly similar patterns hold for three-month forward CIP trading strategy and for IBOR-based forward CIP trading strategies (Appendix Tables A2, A3, and A4). We should note, however, that the mean profit in EUR and CHF forward CIP trading strategies are noisily estimated in all specifications, and that the EUR mean changes sign across specifications. As a result, we cannot say if negative profits from forward CIP trading strategies are associated with funding currencies more broadly or only with the Japanese yen. However, even if the EUR and CHF profits are roughly zero, this stands in contrast to the positive profits associated with higher interest rate currencies.

4.2 Portfolios of Forward CIP Trading Strategy

We next consider the forward CIP trading strategy profits of the classic carry and dollar portfolios (defined in equations (15) and (16)), shown in Panel B of Table 1.

As one might expect from the individual currencies, the pre-crisis mean profits of both the carry and dollar portfolio are close to zero.[12] The annualized post-crisis profits the

[11]The Sharpe ratio of a forward CIP trading strategy is calculated as the average profit per dollar notional divided by the sample standard deviation of the profit per dollar notional, as the profit per dollar notional is analogous to an excess return.

[12]The dollar portfolio's pre-crisis mean would be even closer to zero if we removed the rather-suspect

classic carry portfolio are 14 basis points and are statistically significant. In addition, the Sharp ratio of the classic carry is equal to 1.4, and highly statistically significant. In contrast, the post-crisis profits for the dollar portfolio remain close to zero. We observe similar patterns for the three-month forward OIS basis and for the IBOR bases (Appendix Tables A2, A3, and A4), as well as for alternative constructions of carry and dollar portfolios (Appendix Table A5).

The magnitude of the annualized Sharpe ratios for the classic carry portfolio of 1.4 is high compared to many documented trading strategy returns in the literature. For example, the traditional carry portfolio, which borrows in low interest currency and lends in high interest currency, has an annualized Sharpe ratio of 0.48 when using AUD, CAD, CHF, EUR, GBP, and JPY, from 1987 to 2009. Carry portfolios of up to 20 currencies from 1997 to 2009 have an annualized Sharpe ratio of 0.865. The annualized Sharpe ratio of a value-weighted portfolio of all U.S. stocks from 1976 to 2010 is 0.42 (Burnside et al. (2010), Burnside et al. (2011)).

Our result of high Sharpe ratios for the carry portfolio but not the dollar portfolio is consistent with our model. As we discuss in Section 2, the spot basis that is relevant for intermediaries and should enter the SDF is the one with the largest available arbitrage (in absolute values), adjusted for any differences in risk-weighting in the constraints that affect the intermediary. If we take the view that all cross-currency bases have similar risk weights, this theory predicts the largest spot bases such as AUD-JPY, which remains positive for essentially all of our sample, should be relevant, while smaller bases should not. The dollar portfolio places equal weight on all currencies vs. the U.S. dollar, and hence on many of the smaller spot bases.

Going forward, we will focus our analysis entirely on the forward CIP trading strategy returns of the classic carry portfolio. We will first examine whether these returns are predictable, and then whether they can used to help price other assets.

NZD ois results.

4.3 Forward CIP Trading Strategy's Return Predictability

We next turn to the question of whether the returns of our forward CIP trading strategy are predictable. In the context of the model, as usual, return predictability implies time variation in either the quantity or price of cross-currency basis risk.

We find suggestive evidence that forward CIP trading strategy returns are predictable, in a manner that is analogous to findings of return predictability in the term structure literature (e.g. Campbell and Shiller (1991)). Our approach is inspired by Figure 3; the unconditional returns of the forward CIP trading strategy can be viewed as stating that the increase in the spot bases implied by the forward curves does not end up happening, on average. This result is similar to the familiar concept of a term premium in the term structure literature.

As demonstrated by Campbell and Shiller (1991), the slope of the term structure predicts the excess returns on longer maturity bonds. That is, not only is there a term premium, but it varies over time and variation in the term premium is a significant portion of the variation in the slope of the term structure. We find that a similar fact holds for the term structure of cross-currency bases. In other words, the slope of the term structure predicts forward CIP trading strategy returns.

The return predictability regressions we run are presented in Table 2. The regressions estimate equations of the form

$$x^c_{t,h,\tau} - x^c_{t+h,0,\tau} = \beta(x^c_{t,h,\tau} - x^c_{t,0,\tau}) + \gamma w_t + \epsilon_{t+h}, \tag{17}$$

where w_t are other controls. We use a three-month horizon ($\tau = 3$) and look at one-month forward differences between the forward basis and the spot basis that is actually realized ($h = 1$). We use the "classic carry" basis of AUD vs. JPY in all regressions, although we find but do not report similar results for individual currencies. We estimate the regressions in daily data and rely on a Newey-West HAC kernel with the Newey and West (1994) bandwidth selection procedure to correct the standard errors for overlap in the sample. Note that our outcome variable is not exactly the profit per dollar notional defined in equation (15), because we do not scale the outcome variable by the duration

$\frac{\tau}{12}$. This is analogous to regressing yield changes on yields instead of price changes on yields.

The first column of Table 2 simply regresses the outcome variable on a constant. We estimate an unconditional mean of 5 basis points and a root mean squared error of 12 basis points. In other words, on average, the one-month forward implied three-month classic carry basis is 5 basis points higher than the spot three-month basis one month in the future. The ratio of these two, scaled by $\sqrt{12}$, is essentially our point estimate for the annual Sharpe ratio of the unconditional forward CIP trading strategy.

The next four columns of Table 2 present the estimations of equation (17) with various permutations of two controls, the current level of the spot basis ($x^c_{t,\tau}$) and a constant. Column 4, which uses the spread and the spot basis as predictors, appears to offer a low RMSE while using fewer variables than the specification of column 5.[13] In what follows, we will use column 4 as our preferred specification, although our results are robust to using any of the other specifications instead. The specification in column 4 has the appealing property that, in a world in which both the spot and forward bases are zero (covered interest parity holds), we should expect no return on our forward CIP trading strategy.

Our return predictability results must be interpreted with caution. We usually expect return predictability regressions to require long time series to find significant results. Yet this intuition stems in part from the prior that "good deals" are not available, and that return predictors are very persistent. We find that spreads are not very persistent, and hence that it is possible to find predictability even in our comparatively small sample.

However, this lack of persistence raises another issue. The forward basis $x^c_{t,h,\tau}$ enters both sides of equation (17), and is surely measured with some bid-offer induced noise. This issue is exactly analogous to the role of a price in a regression of return on lagged return (as in Roll (1984)). A standard approach to dealing with these issues is to avoid using the current value of the forward basis as a predictor value, and replace it with a

[13]Formally, the column 4 specification has the lowest value of the Akaike Information Criterion (AIC), where the AIC is computed with a sample size of 98 months to account for overlapping data.

lagged value instead (see, e.g., Jegadeesh (1990)). We adopt this approach, employing a lagged value of the spread, $x^c_{t-k,h,\tau} - x^c_{t-k,\tau}$, as an instrument for the current value of the spread. Columns 6, 7, and 8 of Table 2 repeat the specification of column 4, using a spread lagged 1, 5, and 10 trading days as an instrument for the current spread value. Our return predictability results continue to hold with this approach, and our point estimates remain similar across specifications, although our standard errors increase in the length of the lag.

We should emphasize that this lag approach is not a panacea (Jegadeesh and Titman (1995)). We have no theory on what causes the spread to vary over time, and hence cannot say decisively that the "real" variation dominates the micro-structure induced variation over a one or two-week period.

In our cross-sectional analysis, presented in the next section, we require a time series of surprise basis returns. The results we present will use the specification in column 4 of Table 2, which uses the spread and current spot basis as return predictors, to generate residuals, which we refer to as basis shocks. We find almost identical results when using one of the other specifications in Table 2.

4.4 The Price of Cross-Currency Basis Risk

Before proceeding to our cross-sectional analysis, we discuss how to translate our point estimates to coefficient ξ in our hypothesized SDF. Suppose, for the sake of simplicity, that innovations in the cross-currency basis are uncorrelated with the return on the intermediary's wealth portfolio. In this case, under the our hypothesized form of the stochastic discount factor equation (1), and assuming homoskedasticity, the Sharpe ratio of the forward CIP trading strategy is

$$SR = -\xi\sigma^{|x|},$$

where $\sigma^{|x|}$ is the conditional volatility of the basis shock. The contribution of the basis shock to the volatility of the SDF, under the assumption of no correlation with the wealth return, is of course exactly the Sharpe ratio (Hansen and Jagannathan (1991)).

Because the classic carry spot basis is positive for essentially all of our post-crisis sample, we will use the basis shocks introduced above as proxies for the innovations to $|x_{t+1,1}|$ in our SDF (equation (1)). In Column 1 of Table 2, we find that the unconditional mean is roughly 4.8 basis points/month. Under the assumption of zero correlation between the basis and the return on the wealth portfolio, an asset with a beta of negative ten[14] to the basis will have a return that is roughly forty eight basis points per month higher than an asset with a beta of zero to the basis that is otherwise identical.

In the next section, we test a more sophisticated version of this prediction, attempting to uncover the price of cross-currency basis risk in the cross-section of asset returns.

5 Parameter Estimation and Cross-Sectional Test

In this section we assess whether exposure to the cross-currency basis is a priced risk factor using standard portfolios of test assets. Our exercise builds directly on He et al. (2017) (henceforth, HKM). Currently, we study the returns on equity portfolios (FF, the Fama-French 25 size and value-sorted portfolios, Fama and French (1993)), currency portfolios (FX, developed and EM currencies sorted on interest rates, Lustig et al. (2011)), treasury portfolios (US, the ten maturity-sorted CRSP "Fama Bond Portfolios"), and sovereign bond portfolios (Sov, sorted on credit rating and beta to the stock market, Borri and Verdelhan (2015)). We also study single-currency forward CIP trading strategy returns with OIS and IBOR rates described previously as test assets (OIS-FA and IBOR-FA). We intend to include the remainder of the test assets considered by HKM in future revisions.

The conjecture we are testing, which follows from our hypothesized form of the stochastic discount factor[15], is that

$$E[R^i_{t+1} - R^f_t] = \alpha + \beta^i_w \lambda_w + \beta^i_x \lambda_x, \tag{18}$$

where β^i_w is the beta of asset i to the return on the manager of the intermediary's wealth portfolio and β^i_x is the beta to the basis shock. These betas can be estimated in the

[14]Because the volatility of the basis is on the order of basis points, an asset with a beta of -10 to the basis is not necessarily very correlated with the basis. Note that a negative beta means low returns when the basis becomes large (i.e. bad times).

[15]Our hypothesis is expressed as a linear form for the log SDF, but we test a linear SDF to stay closer to the procedure of He et al. (2017).

standard way using a time series regression,

$$R^i_{t+1} - R^f_t = \mu_i + \beta^i_w (R^w_{t+1} - R^f_t) + \beta^i_x \epsilon^{|x|}_{t+1} + \epsilon^i_{t+1}, \tag{19}$$

where $\epsilon^{|x|}_{t+1}$ is the innovation in our regression that predicts the future values of the spot basis, column 4 of Table 2.

Testing this hypothesis requires an empirical proxy for the return on the manager's wealth portfolio. We consider two proxies, both based on HKM. The first specification follows HKM in decomposing the wealth return into a market return and an innovation to the capital ratio, and allows the price of those two risks to be different; we call this the three-factor SDF. The second specification, which seems closer to both our model and the model referenced in HKM, uses the intermediary equity return index of HKM as a proxy for the return of the manager's wealth portfolio; we call this the two-factor SDF. We note that back-of-the-envelope calculations in the previous section suggest a value for λ_x of roughly -5 basis points per unit beta in both SDF specifications. We also compare our estimation results from the two-factor and three-factor SDFs incorporating the basis factor (as described above), with an SDF that omits the basis factor (the original HKM specifications).

We estimate the prices of risk for the various test asset classes separately and jointly. We present results that estimate equation (18) as a cross-sectional OLS regression, with GMM standard errors to account for the estimation of the betas in equation (19), following chapter 12 of Cochrane (2009).[16]

One key difference between our exercise and the textbook procedures is that the samples we use to estimate the betas and the mean excess returns are quite different. Our model argues that the cross-currency basis enters the pricing kernel because it measures the degree to which regulatory constraints bind, a viewpoint that is only relevant for the post-crisis period. Eight years of data, however, is far too short to reliably determine whether one test portfolio has higher expected returns than another test portfolio. To overcome this difficulty, we estimate the cross-sectional regression using the longest avail-

[16] More efficient (in an asymptotic sense) procedures estimate equations (18) and (19) jointly as moment conditions. These procedures have advantages and disadvantages relative to the cross-sectional approach; see Cochrane (2009).

able sample for each test portfolio, while estimating the betas using only the post-crisis sample. This approach is valid if the long-sample expected excess returns are also the expected excess returns during the post-crises period.[17]

This issue of samples also explains why our various test portfolios may contain information about the price of cross-currency basis risk that is not captured by the forward CIP trading strategy returns. As discussed in Cochrane (2009), pg. 244-5, with a two-step or GLS-type estimation procedure, we would usually find that the risk price associated with a tradable factor is exactly its expected excess return. The explanation for this result is that any other asset provides a more noisy version of the same information. However, in our exercise, the mean return on our forward CIP trading strategy is measured over a small sample period (post-crisis), whereas other mean returns are measured over longer samples. Consequently, these other mean returns provide information not contained in the mean forward CIP trading strategy return.

Lastly, before presenting our results, we should note that our estimates differ in a variety of respects from the main results of HKM. Most importantly, our results are estimated on monthly data, and our betas are estimated only in the post-crisis period. For most of the asset classes we study, our test portfolios are also slightly different. We discuss these details in the appendix, section D.

We present our first set of results are in Table 3. These results use the three-factor SDF, adding the "classic carry" cross-currency basis shock estimated in column 4 of Table 2 to the market and intermediary factor of HKM. For treasury bonds, sovereign bonds, and foreign exchange portfolios (columns 1-3), we estimate risk prices of 6-7 basis points per unit beta of basis shock risk, close to the price implied by the mean return on the forward CIP trading strategy. However, these estimates are imprecise. When we combine these three asset classes into a single regression (column 5), we get a point estimate of almost 10 basis points per unit beta, and can reject the hypothesis that the price is zero.

[17] One possible justification for this assumption follows. Intermediaries purchase assets that historically have high risk-adjusted returns. Consequently, the returns of these assets will co-move with intermediary constraints and hence cross-currency bases during the post-crisis period. That is, the causality can run from the returns to the betas, instead of the other way around.

Using the cross-section of OIS-based forward CIP trading strategy returns (column 6), we estimate a price of risk of 6 basis points, with a small standard error. This result is driven in part by the mean return on the portfolio, because the AUD and JPY forward CIP trading strategies are included as test assets, but also by the price of risk for the other currencies we study. Using the cross-section of IBOR-based forward CIP trading strategy returns (column 7), we arrive at a similar price of risk.

Our results for the treasury bonds, sovereign bonds, FX portfolios, and forward CIP trading strategies are all consistent with the mean return for the classic carry forward CIP trading strategy, and all point to a price of risk of between 5 and 10 basis points per unit beta.

In contrast, for the Fama-French 25 equity portfolios (column 4), we find a risk price with the opposite sign. This finding is consistent with the results of HKM, who also have difficulty pricing equities in their monthly data. Moreover, it is consistent with the view espoused by those authors that intermediaries are unlikely to be the marginal agents in equity markets. In the context of our model, a binding regulatory constraint can cause the intermediary SDF to fail to price equities if the risk weight associated with equities is high relative to other asset classes.

In the last column of Table 3, we use our single-currency OIS-based forward CIP trading strategy returns as test assets with the original HKM pricing factors. The HKM intermediary pricing factor is strongly priced in the cross-section of forward CIP trading strategy returns. Moreover, comparing Table 3 and Appendix Table A6, we observe that the presence of the basis shock factor substantially attenuates the price of the HKM pricing factor.[18] Both of these observations are consistent the idea that the shocks to the HKM intermediary factor and shocks to the cross-currency basis factor co-move significantly. In Figure 6, we present a time series of the spot classic carry AUD-JPY basis and the HKM factor.[19]

[18]This comparison is not quite "apples-to-apples," because most of the betas of in Table A6 are computed on a longer sample, as there is no reason to restrict the beta estimation sample to the post-crisis period.

[19]In Appendix Figure A3, we show that the time series of other carry factors constructed using more currencies are very close to the time series of the classic carry, the AUD-JPY basis. Definitions of different

It is apparent in Figure 6 that innovations to the spot classic carry basis and the HKM intermediary factor are (negatively) correlated. We interpret this result as suggesting that much of the variation in the cross-currency basis is driven by shocks to intermediary wealth or investment opportunities. However, we also note that our basis factor exhibits an upward trend in recent years, which may be attributable to changes in regulation (e.g. the implementation of Basel III).

The significance of the basis shock factor relative to the HKM intermediary factor in Table 3 suggests that, although the two are correlated, either the basis shock is measuring something the HKM factor is not or that it is more precisely measuring the parameter of interest. In the context of our model, both considerations are possible. The HKM intermediary factor might be a proxy for the manager's wealth portfolio return; however, it is also isomorphic to a book-to-market ratio and therefore might also be expected to predict future returns on the manager's wealth portfolio, and hence be related to intertemporal hedging. Our use of the basis shock as a factor is also motivated by intertemporal hedging, and therefore it is not entirely surprising that the two factors are correlated. Broadly speaking, it is reassuring for intermediary asset pricing theory that measures of intermediary wealth like the HKM factor and measures of intermediary constraints like our basis shock move together.

Table 4 presents our second set of results, which use the HKM intermediary equity return as the sole proxy for the intermediary manager's wealth portfolio return. The coefficients on the basis shock factor are generally very close to their counterparts from Table 3.[20] The coefficients on the intermediary equity return are also broadly consistent across asset classes, and statistically significant. As mentioned by HKM, and especially in monthly data, the innovations to the HKM intermediary factor and the returns on intermediary equity are highly correlated, and hence it is not surprising that the results are similar.

carry portfolios are in Appendix E

[20]The coefficient on US is quite different, but noisily estimated. The US treasury bond portfolios have a very strong factor structure to their returns, which makes them less-than-ideal test assets, a point made by HKM.

6 Discussion and Conclusion

We provide direct evidence (risk premia on forward CIP trading strategies) and indirect evidence (cross-sectional asset pricing) that the classic carry cross-currency basis is correlated with the stochastic discount factor. These results are consistent with our motivating hypothesis, derived from an intermediary-based asset pricing framework and intertemporal hedging considerations.

Taken together, we view our results as strongly supportive of intermediary-based asset pricing theory. Any alternative theory that seeks to explain our results would have to overcome three challenges. First, the theory would have to rationalize the existence of arbitrage (the cross-currency basis). Second, the theory would have to explain why there is a risk premium associated with the arbitrage becoming larger (the forward CIP trading strategy returns). Third, the theory would have to explain why forward CIP trading strategy returns co-move with measures of intermediary wealth, and why co-movement with forward CIP trading strategy returns can help explain cross-sectional variation in expected returns among asset classes in which intermediaries are key participants, but not within equities.

More broadly, we view this paper as beginning an investigation in the dynamics and pricing of arbitrages induced by regulatory constraints. If intermediaries play a central role in both asset pricing and the broader economy, then the question of how to measure the constraints they face and the properties of those constraints is of first-order importance.

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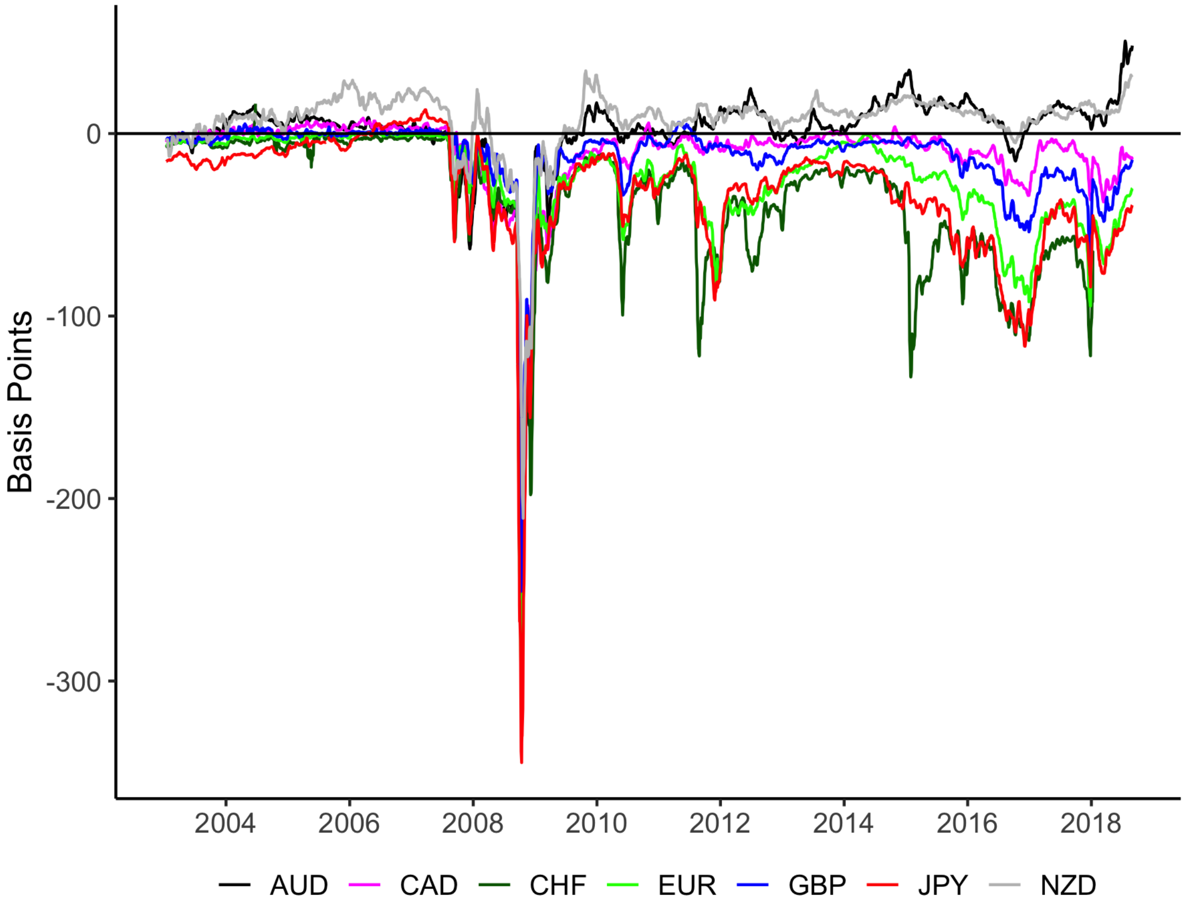
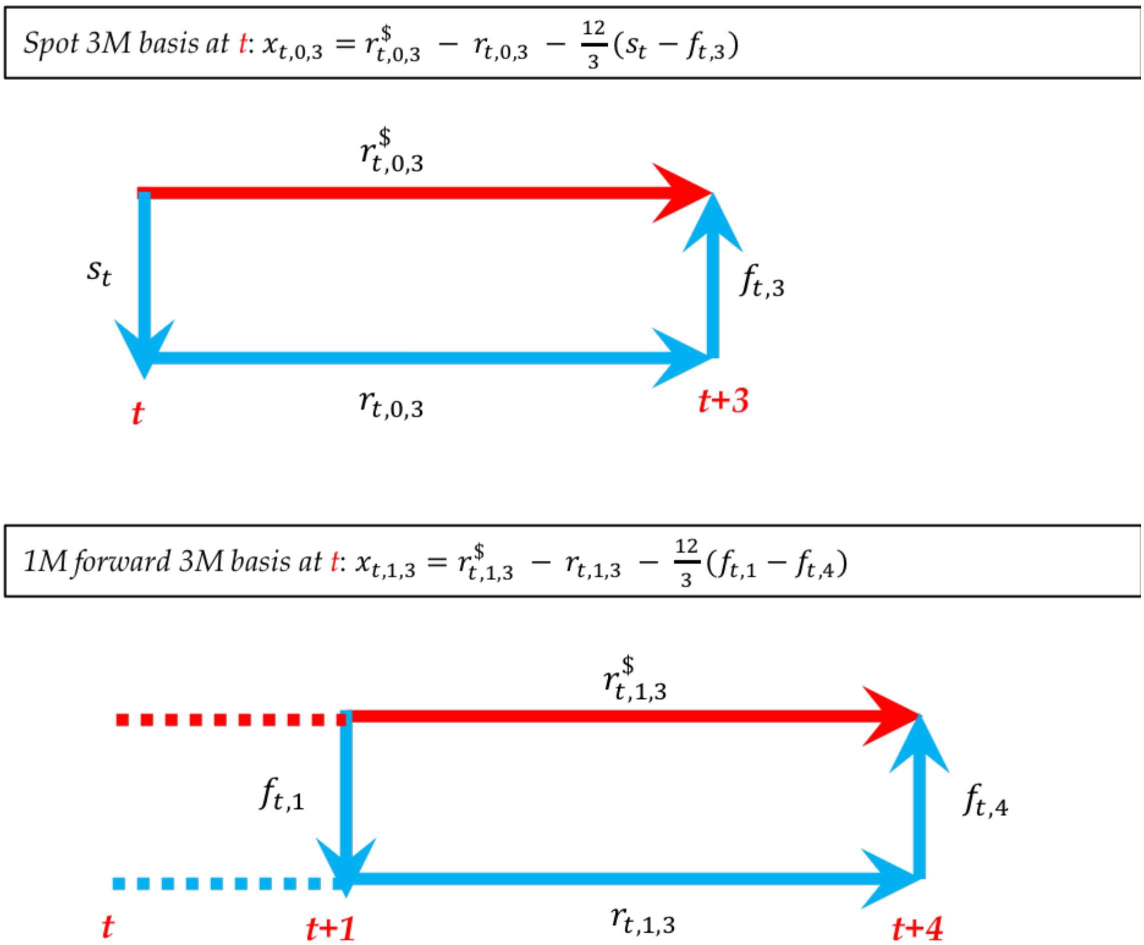
Figures and Tables

Figure 1: **Three-month OIS-based Cross-Currency Bases**



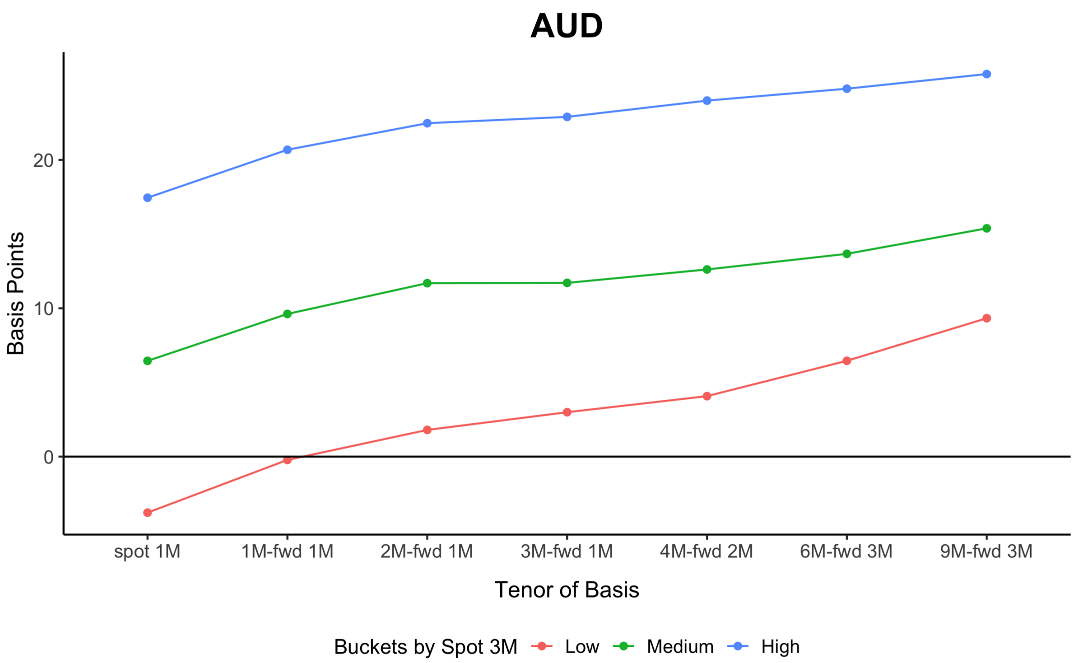
This figure plots the 10-day moving average of daily spot 3M OIS cross-currency basis, measured in basis points, for the seven sample currencies. The spot OIS basis is $x^c_{t,0,3}$, as defined in the text.

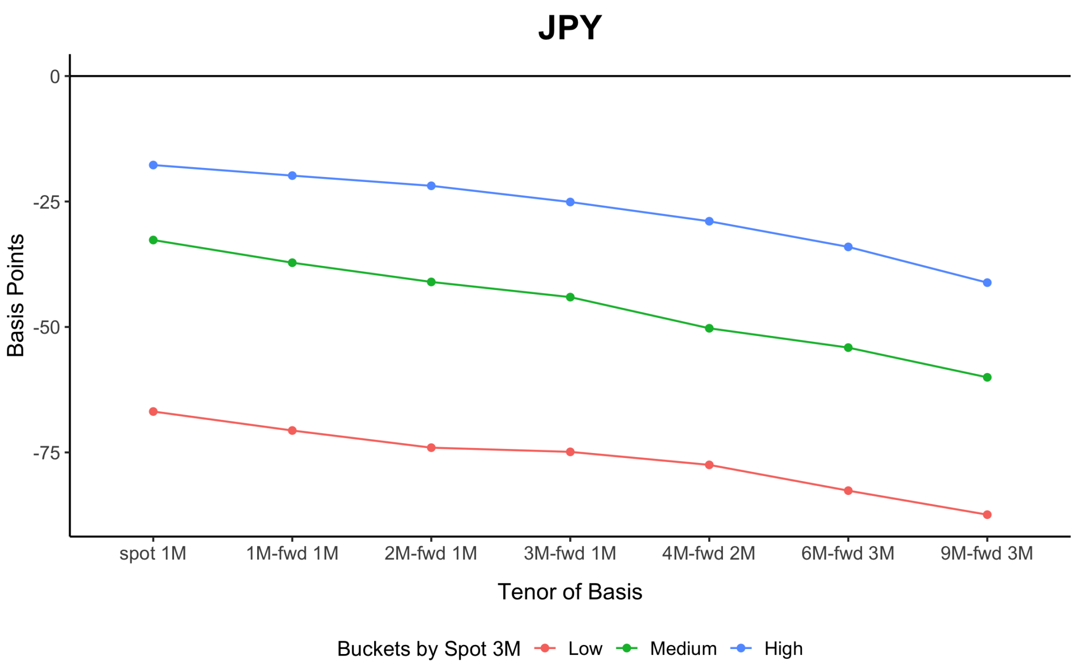
Figure 2: **Illustration of the spot vs. forward cross-currency basis**



This figure illustrates the spot three-month cross-currency basis and the one-month-forward three-month cross-currency basis. The spot basis is $x_{t,0,3}$ as defined in the text, and the forward basis is $x_{t,1,3}$ as defined in the text.

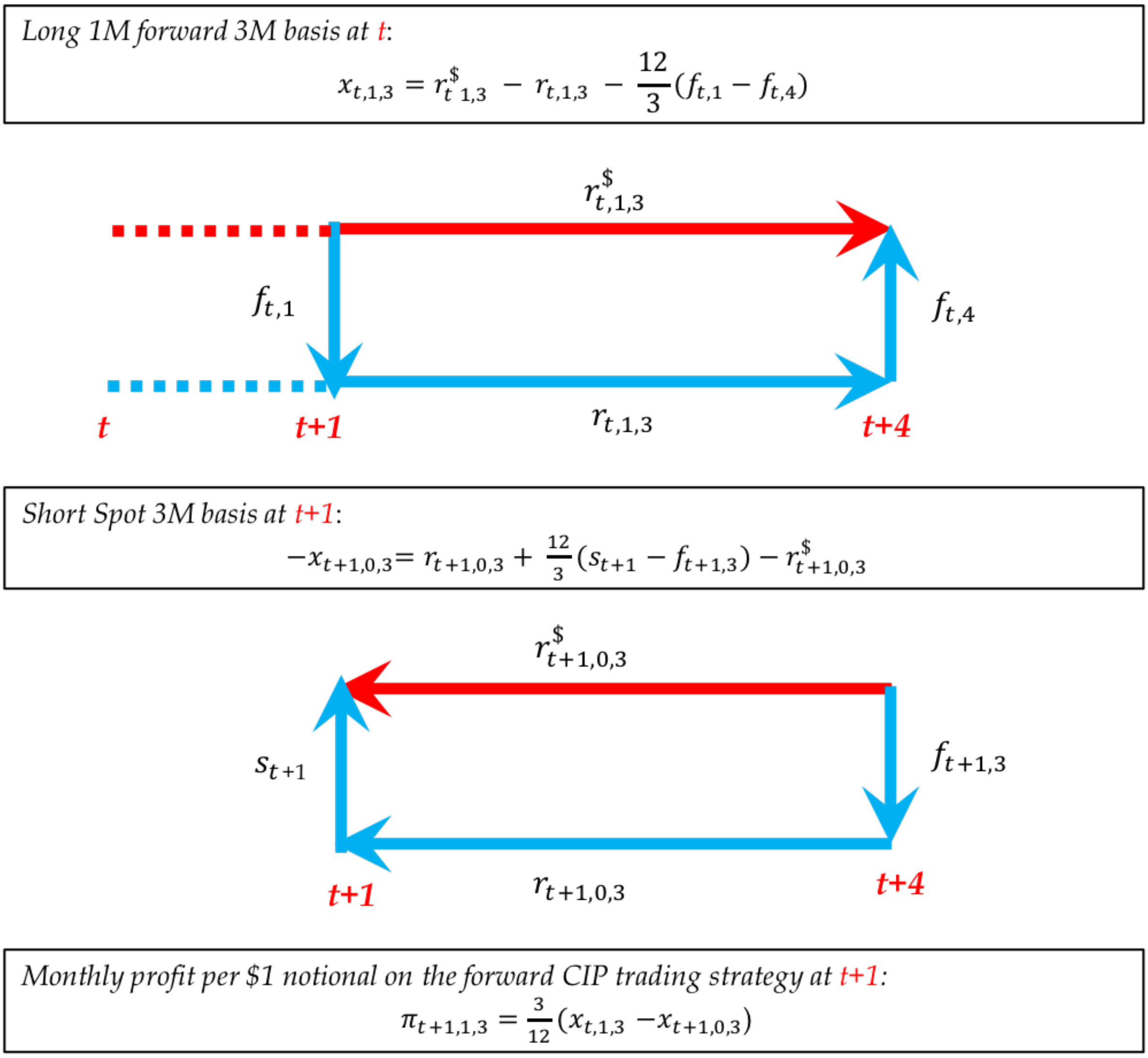
Figure 3: **Term structure of the forward cross-currency basis**





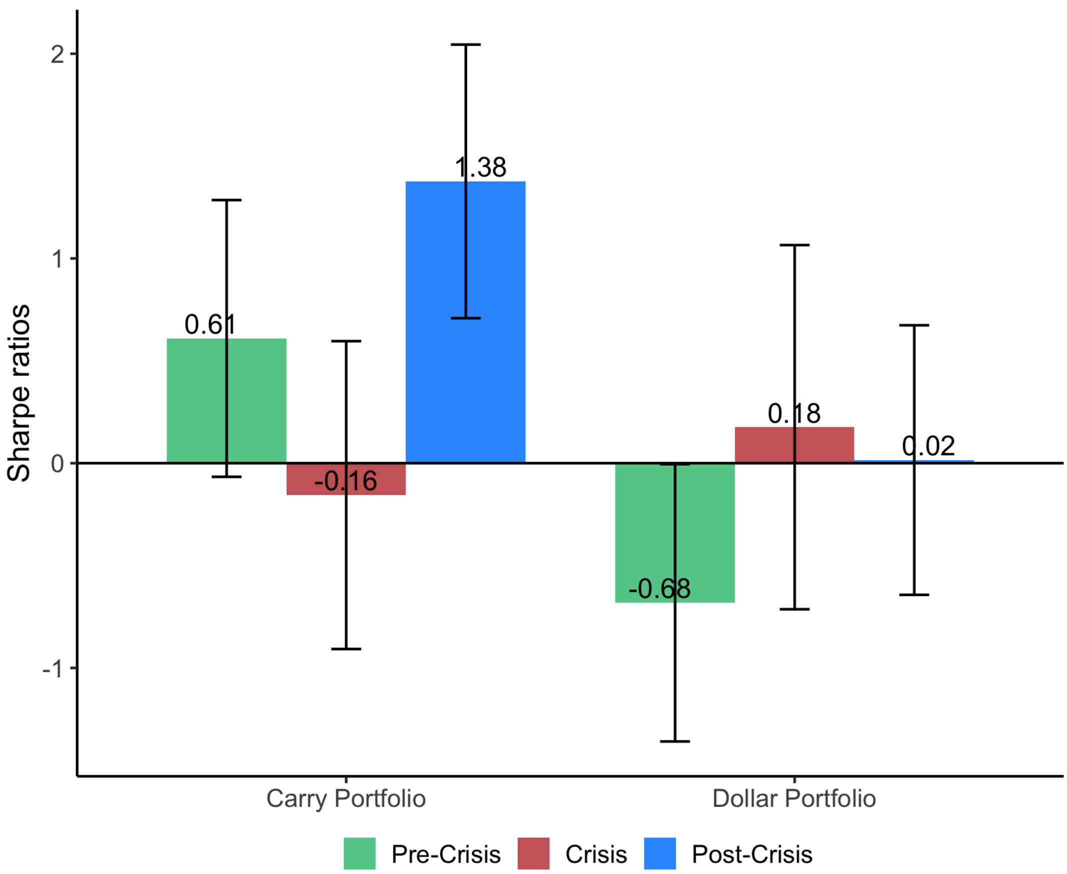
This figure illustrates the time series average spot and forward-starting cross-currency bases in AUD and JPY. For each currency, the sample from July 2010 to August 2018 is split into three sub-samples based on the tercile of the level of the spot 3M OIS cross-currency basis. Within each sub-sample, the time series average of the relevant spot/forward OIS cross-currency basis is shown.

Figure 4: **Illustration of the profit on forward CIP trading strategy**



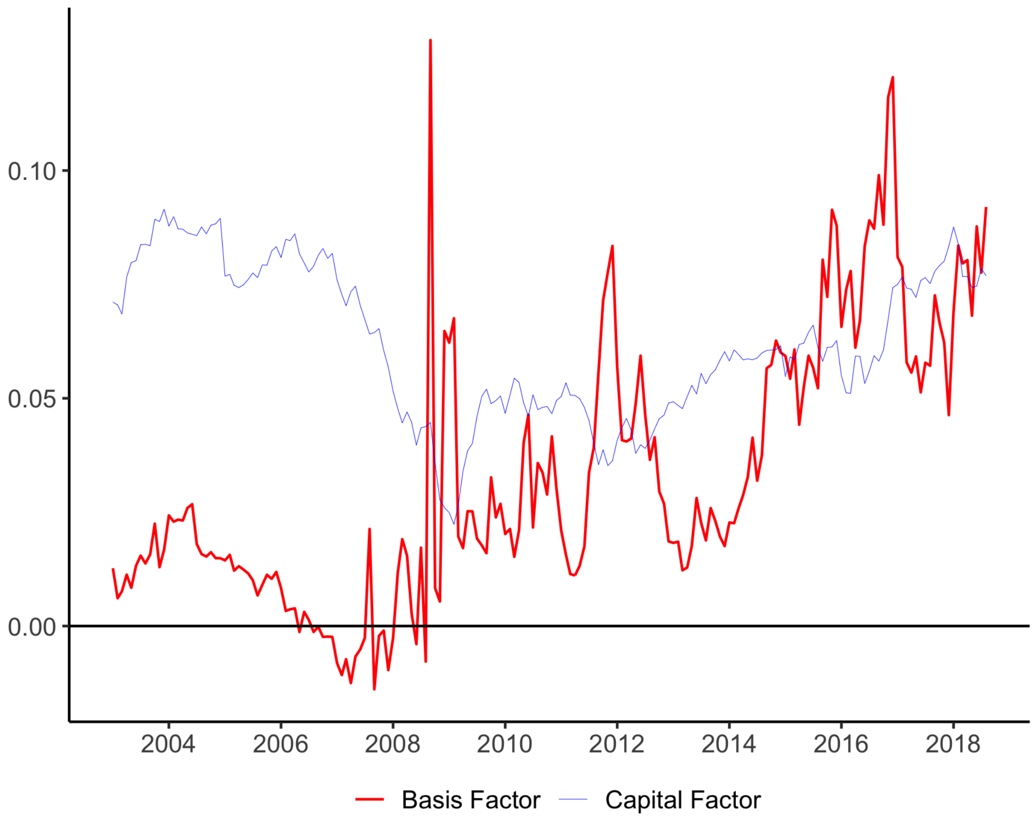
This figure illustrates the return on a one-month-forward three-month forward arbitrage. At time t, the trader enters the forward basis, $x_{0,1,3}$, which is the forward direct interest less the forward synthetic interest. At time $t+1$, the trader unwinds the spot basis, $-x_{1,0,3}$, which is the spot synthetic interest less the spot direct interest. The realized monthly profit per dollar notional on this forward arbitrage is the sum of the two bases: $x_{0,1,3} + (-x_{1,0,3})$, normalized by the duration $3/12$.

Figure 5: **Sharpe ratios of returns from trading portfolios of 1M-forward 3M forward arbitrages**



This figure plots the annualized Sharpe ratios of returns from trading monthly-rebalanced portfolios of forward arbitrages, by weighting scheme and by periods. Error bars indicate the 95% confidence interval, using standard errors calculated with Newey-West correction for overlapping returns. The three periods of analysis are defined as: Pre-Crisis is 2003-01-01 to 2007-06-30, Crisis is 2007-07-01 to 2010-06-30, and Post-Crisis is 2010-07-01 to 2018-08-31. The Carry portfolio is formed by longing the AUD and shorting the JPY forward CIP trading strategy. The Dollar portfolio is formed by going long in all seven sample currencies' forward CIP trading strategy in equal weight.

Figure 6: **The Basis Factor vs. HKM Capital Factor**



This figure plots the monthly basis factor and HKM capital factor from 2003 to August 2018. The basis factor is the spot 3M OIS basis, carry-weighted, and scaled by 10. The HKM capital factor is the intermediary capital ratio.

Table 1: **Summary Statistics of Returns on OIS 1M-forward 3M Forward CIP Trading Strategy**

Panel A: Single Currencies						
	Mean			Sharpe Ratio		
	Pre-Crisis	Crisis	Post-Crisis	Pre-Crisis	Crisis	Post-Crisis
AUD	1.06	3.71	4.71**	0.28	0.10	0.90**
	(0.97)	(17.47)	(1.71)	(0.26)	(0.45)	(0.31)
CAD	-0.92	1.50	5.57***	-0.26	0.05	1.10***
	(1.21)	(14.72)	(1.50)	(0.34)	(0.46)	(0.31)
CHF	-1.33	6.64	-3.61	-0.34	0.16	-0.25
	(0.76)	(19.01)	(4.58)	(0.18)	(0.42)	(0.35)
EUR	-1.15*	14.29	-1.35	-0.60*	0.34	-0.18
	(0.51)	(19.49)	(2.43)	(0.28)	(0.39)	(0.32)
GBP	-1.47*	9.27	4.19**	-0.48	0.27	0.82*
	(0.72)	(15.73)	(1.59)	(0.26)	(0.41)	(0.35)
JPY	-2.01*	8.18	-9.51**	-0.82*	0.17	-1.04***
	(0.88)	(22.10)	(2.95)	(0.36)	(0.43)	(0.31)
NZD	-7.06***	-1.70	0.27	-1.03***	-0.06	0.07
	(1.62)	(12.93)	(1.14)	(0.21)	(0.46)	(0.27)

Panel B: Portfolios						
	Mean			Sharpe Ratio		
	Pre-Crisis	Crisis	Post-Crisis	Pre-Crisis	Crisis	Post-Crisis
Carry	2.44	-4.37	14.25***	0.61	-0.16	1.38***
	(1.34)	(10.79)	(3.26)	(0.34)	(0.38)	(0.33)
Dollar	-1.46	6.16	0.07	-0.68*	0.18	0.02
	(0.77)	(16.53)	(1.52)	(0.34)	(0.44)	(0.33)

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table reports the annual profits and annualized Sharpe ratios from the OIS 1M-forward 3M forward CIP trading strategy. All statistics are reported by period: Pre-Crisis is 2003-01-01 to 2007-06-30, Crisis is 2007-07-01 to 2010-06-30, and Post-Crisis is 2010-07-01 to 2018-08-31. Panel A reports results in single currencies. Panel B reports results in portfolios of single currency forward CIP trading strategy. The Carry portfolio is formed by longing the AUD and shorting the JPY forward CIP trading strategy. The Dollar portfolio is formed by going long in all seven sample currencies' forward CIP trading strategy in equal weight. Newey-West standard errors are reported in parenthesis, where the overlapping bandwidth is chosen by the Newey-West (1994) selection procedure.

Table 2: **Forward Arbitrage Return Predictability**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1mFwd3m-3m Spread		0.710***	0.554***	0.509***	0.584***	0.507***	0.588**	0.772*
		(0.127)	(0.122)	(0.106)	(0.113)	(0.127)	(0.194)	(0.303)
Spot Basis 3m				0.0534*	0.0945*	0.0533*	0.0469	0.0339
				(0.0208)	(0.0396)	(0.0225)	(0.0272)	(0.0355)
Constant	0.0476***		0.0202		-0.0300			
	(0.0113)		(0.0111)		(0.0207)			
RMSE	0.119	0.115	0.114	0.112	0.112	0.112	0.112	0.114
R^2	0.137	0.196	0.211	0.237	0.246	0.237	0.237	0.218
NW BW (bus. days)	40	40	40	40	40	40	40	40
1st Stage F						1005.0	153.0	61.48
Instrument Lag (bus. days)						1	5	10
Observations	2099	2099	2099	2099	2099	2092	2092	2092

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table reports return predictability regressions for the classic carry (AUD-JPY) forward arbitrage strategy. The outcome variable in all columns is the one-month return of the three-month OIS forward arbitrage strategy. All data is daily and post-crisis (2010-07-01 to 2018-08-30). 1mFwd3m-3m Spread is the spread between the 1-month forward three-month classic carry basis and the spot three-month classic carry basis. Spot Basis 3m is the spot three month classic carry basis. RMSE is the root-mean-squared error, R^2 is the un-centered R^2, NW BW is the bandwidth chosen by the Newey-West bandwidth selection procedure, 1st Stage F is the F-statistic from the first stage for the IV regressions (see Stock and Yogo (2005)), and Instrument Lag is the number of business days the spread variable is lagged in the IV regression. Units are in percentage points.

Table 3: **Cross-sectional Asset Pricing Tests, 3-Factor.**

	(1) US	(2) Sov	(3) FX	(4) FF	(5) US/Sov/FX	(6) OIS-FA	(7) IBOR-FA	(8) OIS-FA
Market	3.426**	0.536	0.789***	-0.132	0.709*	-4.813*	-3.548	-3.817***
	(1.141)	(0.456)	(0.221)	(0.498)	(0.317)	(1.922)	(3.057)	(0.471)
HKM Factor	-0.114	1.812	0.322	0.432	0.510	-1.161	-1.537	1.606***
	(1.978)	(1.002)	(1.039)	(0.529)	(0.378)	(1.423)	(1.586)	(0.157)
Basis Shock	-0.0739	-0.0695	-0.0627	0.0339	-0.0973***	-0.0630***	-0.0558***	
	(0.0968)	(0.0446)	(0.0381)	(0.0329)	(0.0287)	(0.0105)	(0.0154)	
Intercepts	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MAPE (N (assets)	10	6	11	25	27	7	7	7
N (beta, mos.)	98	98	98	98		98	98	98
N (mean, mos.)	224	283	418	1106		98	98	98

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table reports cross-sectional asset pricing tests for various asset classes. Mkt and HKM factor and two factors employed by He et al. (2017), and basis shock is the residual of the return predictability regression on the classic carry forward arbitrage return in column 4 of Table 2. Intercepts indicates an intercept is used for each asset class (one intercept per column, with 3 in column 5). MAPE is mean absolute pricing error of monthly returns. The asset classes are described in Appendix Section D. Standard errors are computed using GMM with the Newey-West kernel and bandwidth selection procedure (Newey and West (1994)). Units are in percentage points.

Table 4: **Cross-sectional Asset Pricing Tests, 2-Factor.**

	(1) US	(2) Sov	(3) FX	(4) FF	(5) US/Sov/FX	(6) OIS-FA	(7) IBOR-FA	(8) OIS-FA
Int. Equity	2.971	1.591***	1.756***	0.636	1.478***	-0.973*	-1.996***	2.000***
	(1.747)	(0.467)	(0.392)	(0.431)	(0.330)	(0.381)	(0.590)	(0.121)
Basis Shock	-0.349**	-0.0819	-0.0759	0.0195	-0.100**	-0.0535***	-0.0615***	
	(0.130)	(0.0590)	(0.0508)	(0.0358)	(0.0321)	(0.00212)	(0.00455)	
Intercepts	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MAPE (N (assets)	10	6	11	25	27	7	7	7
N (beta, mos.)	98	98	98	98		98	98	98
N (mean, mos.)	224	283	418	1106		98	98	98

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table reports cross-sectional asset pricing tests for various asset classes. Int. Equity is the value-weighted intermediary equity return of He et al. (2017), and basis shock is the residual of the return predictability regression on the classic carry forward arbitrage return in column 4 of Table 2. Intercepts indicates an intercept is used for each asset class (one intercept per column, with 3 in column 5). MAPE is mean absolute pricing error of monthly returns. The asset classes are described in Appendix Section D. Standard errors are computed using GMM with the Newey-West kernel and bandwidth selection procedure (Newey and West (1994)). Units are in percentage points.

Appendix

A Equivalent definition of the Forward CIP basis

In this section, we show the equivalence between the two definitions for the forward cross-currency basis given by equations (13) and (14), under the assumption of no-arbitrage between forward interest swap rates and term structure of spot interest swap rates.

$$
\begin{aligned}
x_{t,h,\tau} &= r^{\$}_{t,h,\tau} - r^{c}_{t,h,\tau} - \frac{12}{\tau}(f_{t,h+\tau} - f_{t,h}) \\
&= \left(\frac{h+\tau}{\tau} r^{\$}_{t,0,h+\tau} - \frac{h}{\tau} r^{\$}_{t,0,\tau}\right) - \left(\frac{h+\tau}{\tau} r^{c}_{t,0,h+\tau} - \frac{h}{\tau} r^{c}_{t,0,\tau}\right) - \frac{12}{\tau}(f_{t,h+\tau} - f_{t,h}) \\
&= \frac{h+\tau}{\tau}\left[(r^{\$}_{t,0,h+\tau} - r^{c}_{t,0,h+\tau}) - \frac{12}{h+\tau}(f_{t,h+\tau} - s_t)\right] \\
&- \frac{h}{\tau}\left[(r^{\$}_{t,0,h+\tau} - r^{c}_{t,0,h+\tau}) - \frac{12}{\tau}(f_{t,\tau} - s_t)\right] \\
&= \frac{h+\tau}{\tau} x_{t,0,h+\tau} - \frac{h}{\tau} x_{t,0,h},
\end{aligned}
$$

where the second equality follows no arbitrage between forward interest swap rates and the term structure of spot interest swap rates. This no-arbitrage condition likely holds in practice because arbitrage between interest rate derivatives is not strongly affected by most real-world regulatory constraints. It holds in our model under the assumption that derivatives are not subject to the regulatory constraint.

B Profit Calculations

In this section we detail the calculation of profits for the forward arbitrage trading strategy, and then show how that can be mapped to the cross-currency basis variables we have defined. We will use yen as our example currency.

At time t, the strategy

1. receives fixed (pays floating) on one dollar notional of a h-month forward-starting τ-month interest-rate swap in dollars at annualized fixed rate $R^{\$}_{t,h,\tau}$,
2. enters into a h-month forward agreement to sell $F_{t,h}$ yen in exchange for one dollar,
3. pays fixed (receives floating) on $F_{t,h}$ yen notional of a h-month forward-starting τ-month interest-rate swap in dollars at rate $R^{c}_{t,h,\tau}$, and
4. enters into a $h+\tau$-month forward agreement to buy $F_{t,h}(R^{c}_{t,h,\tau})^{\frac{\tau}{12}}$ yen in exchange for dollars at the exchange rate $F_{t,h+\tau}$.

At time $t+h$, the strategy is unwound. The trader

1. unwinds the receive-fixed dollar swap, earning $(\frac{R^{\$}_{t,h,\tau}}{R^{\$}_{t+h,0,\tau}})^{\frac{\tau}{12}} - 1$ dollars,

2. cash-settles the h-month forward, earning $\frac{S_{t+h}-F_{t,h}}{S_{t+h}}$ dollars,

3. unwinds the pay-fixed swap, earning $\frac{F_{t,h}}{S_{t+h}}(1 - (\frac{R^{c}_{t,h,\tau}}{R^{c}_{t+h,0,\tau}})^{\frac{\tau}{12}})$ dollars, and

4. unwinds the $h+\tau$-month forward, earning $(\frac{1}{F_{t+h,\tau}} - \frac{1}{F_{t,h+\tau}})\frac{F_{t,h}(R^{c}_{t,h,\tau})^{\frac{\tau}{12}}}{(R^{\$}_{t+h,0,\tau})^{\frac{\tau}{12}}}$.

In this last expression, we have used $R^{\$}_{t+h,0,\tau}$ as the discount rate on the forward profits (converted to dollars). In our model, because derivatives are unaffected by the regulatory constraint, the dollar risk-free rate is in indeed the correct discount rate for the forward profits. If net derivative profits affected the regulatory constraint, the appropriate discount rate would depend on questions like whether the trader could unwind or net the derivatives instead of simply taking an offsetting position. However, as a practical matter, the choice of discount rate has a minuscule effect on the computed profits.

Therefore, total profit per dollar notional (i.e. the excess return) is

$$\Pi^{c}_{t+h,h,\tau} = (\frac{R^{\$}_{t,h,\tau}}{R^{\$}_{t+h,0,\tau}})^{\frac{\tau}{12}} - \frac{F_{t,h}}{S_{t+h}}(\frac{R^{c}_{t,h,\tau}}{R^{c}_{t+h,0,\tau}})^{\frac{\tau}{12}} + (\frac{1}{F_{t+h,\tau}} - \frac{1}{F_{t,h+\tau}})(\frac{R^{c}_{t,h,\tau}}{R^{\$}_{t+h,0,\tau}})^{\frac{\tau}{12}} F_{t,h}.$$

Recall the definition of the cross-currency basis,

$$(R^{c}_{t+h,0,\tau})^{\frac{\tau}{12}} S_{t+h} = \frac{(R^{\$}_{t+h,0,\tau})^{\frac{\tau}{12}} F_{t+h,\tau}}{(1 + X^{c}_{t+h,0,\tau})^{\frac{\tau}{12}}}$$

and

$$(R^{c}_{t,h,\tau})^{\frac{\tau}{12}} F_{t,h} = \frac{(R^{\$}_{t,h,\tau})^{\frac{\tau}{12}} F_{t,h+\tau}}{(1 + X^{c}_{t,h,\tau})^{\frac{\tau}{12}}}.$$

Plugging in these definitions,

$$\Pi^{c}_{t+h,h,\tau} = (\frac{R^{\$}_{t,h,\tau}}{R^{\$}_{t+h,0,\tau}})^{\frac{\tau}{12}} \left\{ 1 - \frac{F_{t,h+\tau}}{F_{t+h,\tau}}(\frac{1 + X^{c}_{t+h,0,\tau}}{1 + X^{c}_{t,h,\tau}})^{\frac{\tau}{12}} + (\frac{F_{t,h+\tau}}{F_{t+h,\tau}} - 1)\frac{1}{(1 + X^{c}_{t,h,\tau})^{\frac{\tau}{12}}} \right\}.$$

This exact profit formula is complicated by a variety of discounting effects that arise in the presence of arbitrage. Note, however, that all of these effects (deviations of interest rates and forward exchange rates from their previous forward values) are typically at most a few hundred basis points. In the presence of cross-currency basis values that on the order of basis points, these discounting effects will be a couple percent of some basis points, and hence for the most part negligible.

We therefore employ a first-order approximation. Define

$$\epsilon^F_{t+h,h,\tau} = \ln\left(\frac{F_{t+h,\tau}}{F_{t,h+\tau}}\right),$$

$$\epsilon^R_{t+h,h,\tau} = \ln\left(\frac{R^{\$}_{t+h,\tau}}{R^{\$}_{t,h,\tau}}\right).$$

Taking a first-order expansion around $x^c_{t,h,\tau} = x^c_{t+h,\tau} = \epsilon^F_{t+h,h,\tau} = \epsilon^R_{t+h,h,\tau} = 0$, we have

$$\Pi^c_{t+h,h,\tau} \approx \pi^c_{t+h,h,\tau} = \frac{\tau}{12}(x^c_{t,h,\tau} - x^c_{t+h,0,\tau}),$$

which is the formula employed in the main text.

C Model Details

In this appendix section we present a more careful derivation of the model results described in Section 2. We describe the manager's preferences and problem, then derive the Euler equations and intertemporal asset pricing equations presented in the main text. The model is partial equilibrium, in that it only considers the manager's problem, and is based on He and Krishnamurthy (2011).

The manager is endowed with the ability to run an intermediary that survives for a single period. In the beginning of the period, the manager will raise funds from households in the form of both debt and equity, subject to various constraints, and choose how much of her own wealth to contribute. The manager then invests these funds in a variety of assets. At the end of the period, returns realize and the intermediary is dissolved. The manager receives a payout based on her equity share in the intermediary. This payout, plus any savings the manager holds outside the intermediary, determine the manager's wealth entering into the next period.

Let W^M_t denote the manager's wealth at the beginning of period t, and let z_t be a state variable that determines the conditional (on time t information) distribution of asset returns. These two variables are the state variables of the manager's optimization problem.

At the beginning of the period, the manager must decide on a contractual structure for the intermediary she runs. The intermediary begins by raising equity capital $N_t \geq 0$. Of the initial equity capital, N^M_t is contributed by the manager, with the remainder coming from households. The manager receives are share ϕ_t of the wealth that will be liquidated when the intermediary is dissolved at the end of the period, with the remainder going to households. Note that that the share ϕ_t is not necessarily equal to the proportion of the equity that the manager contributes; define the fee

$$f^m_t \equiv \frac{\phi_t N_t}{N^M_t}$$

as the ratio of what the manager receives to what she contributes.

The manager raises equity and debt from households in a competitive market. Let M^H_{t+1} be the household's SDF, and let $\hat{N}_{t+1}$ be the value of the intermediary's equity after returns are realized and the debt is repaid (we define this variable in more detail below). Let B_t be the face value of the intermediary's debt, and let R^b_t be its interest rate. For any capital structure $(\phi_t, N^M_t, N_t, B_t, R^b_t)$ proposed by a manager with wealth W^M_t in state z_t, households will be willing to purchase the equity if

$$N_t - N^M_t \leq (1 - \phi_t)E[M^H_{t+1}\hat{N}_{t+1}|z_t, W^M_t, (\phi_t, N^M_t, N_t, B_t, R^b_t)].$$

We assume that the debt is priced by the household's SDF,

$$1 = E[M^H_{t+1}R^b_t|z_t].$$

Note that the expectation is conditional on the state variables z_t, W^M_t and the capital structure of the intermediary, but not on the intermediary's asset allocation (which we define below). That is, the household must form a conjecture about what the manager will choose to invest, and price the equity accordingly; the manager cannot commit. This is a key friction, which is also employed by He and Krishnamurthy (2011).

We have assumed that the intermediary is risk-free. We are ignoring the possibility of default; the model of He and Krishnamurthy (2011) that we are building on is developed in continuous time with continuous price processes, and hence also excludes the possibility of default. We develop a discrete time model to make the intuition behind our hypothesized SDF clear, and have found that incorporating the possibility of default obfuscates that intuition.[21]

We next turn to the intermediary's budget constraints. We allow the manager of the intermediary to divert resources from the intermediary instead of investing them. Let $\Delta_t \geq 0$ be the resources diverted. In equilibrium, households will ensure that diversion does not occur by ensuring that ϕ_t, the manager's claim on the assets, is sufficiently high.

Let I be the set of all assets available to the intermediary. We partition this set into "cash" and "derivative" assets, I^c and I^d, assuming that the former require an upfront cash investment whereas the latter are contracts entered into with zero initial net-present-value. The distinction between these two groups of assets is that the former affects the intermediary's initial budget constraint, whereas the latter does not. Let α^i_t be the dollar amount (cash) or notional (derivative) invested in asset i, scaled by the initial non-diverted intermediary equity N_t.

The intermediary's initial budget constraint is

$$N_t + B_t = \Delta_t + N_t \sum_{i \in I^c} \alpha^i_t.$$

[21]Note, however, that incorporating the possibility of default is necessary for the model to speak to issues like whether is to preferable to examine OIS or IBOR bases. Because our model is silent on these issues, we have chosen to emphasize only results that are robust to the choice OIS vs. IBOR.

The excess return (cash assets) or profit per unit notional (derivative assets) of asset i is defined as $R^i_{t+1} - R^b_t$. The distribution of these returns is a function of z_t, and the returns are realized at the end of the period. The intermediary's net worth when it is liquidated at the end of the period is therefore

$$\hat{N}_{t+1} = -R^b_t B_t + N_t \sum_{i \in I^c} \alpha^i_t R^i_{t+1} + N_t \sum_{i \in I^d} \alpha^i_t (R^i_{t+1} - R^b_t),$$

which can be re-written as

$$\hat{N}_{t+1} = R^b_t (N_t - \Delta_t) + N_t \sum_{i \in I} \alpha^i_t (R^i_{t+1} - R^b_t).$$

Using this definition, we can rewrite the household's equity participation constraint as

$$\begin{aligned} N_t - N^M_t \leq & (1 - \phi_t)(N_t - \Delta^*_t) \\ & + N_t (1 - \phi_t) E[M^H_{t+1} \sum_{i \in I} \alpha^{i*}_t (R^i_{t+1} - R^b_t) | z_t]), \end{aligned}$$

where Δ^*_t and α^{i*}_t are the policies that the household conjectures based on observing the state variables and capital structure.

Lastly, as described in the text, we assume that the intermediary operates under a regulatory constraint that affects only cash assets:

$$1 \geq \sum_{i \in I^c} k^i |\alpha^i_t|.$$

Note that we have assumed that the regulatory constraint cannot limit the cashflow diversion of the manager.[22]

These constraints describe the operation of the intermediary. We next turn to the decisions and preference of the manager. We assume the manager has CRRA preferences, with risk-aversion γ, over her consumption, C^M_t, and a subjective discount factor of β. Whatever wealth she does not consume or invest in the intermediary, plus any resources she diverts from the intermediary, is saved in risk-free assets, but the manager cannot borrow. When the manager diverts Δ_t resources from the intermediary, she receives only $(1+\psi)^{-1}\Delta_t$, which she can save in the risk-free asset. As a result, her wealth entering the next period is

$$W^M_{t+1} = R^b_t (W^M_t - C^M_t - N^M_t + \frac{\Delta_t}{1+\psi}) + \phi_t \hat{N}_{t+1},$$

where the first term represents the intermediary's outside savings and the second her

[22]Our model inherits from He and Krishnamurthy (2017) the somewhat awkward assumption that the manager cannot commit when choosing an asset allocation, even though the regulator can limit the manager's asset allocation.

share of the intermediary's liquidation value.

We now define the Bellman equation describing the manager's problem. The manager solves

$$\begin{aligned} V(W_t^M, z_t) = &\max_{C_t^M \geq 0, N_t^M \geq 0, N_t \geq 0, \phi_t \in [0,1], \Delta_t \geq 0, \{\alpha_t^i\}_{i \in I}} \frac{(C_t^M)^{1-\gamma}}{1-\gamma} \\ &+ \beta E[V(W_{t+1}^M, z_{t+1}) | z_t], \end{aligned}$$

subject to

$$\begin{aligned} \hat{N}_{t+1} &= R_t^b (N_t - \Delta_t) + N_t \sum_{i \in I} \alpha_t^i (R_{t+1}^i - R_t^b), \\ W_{t+1}^M &= R_t^b (W_t^M - C_t^M - N_t^M + \frac{\Delta_t}{1+\psi}) + \phi_t \hat{N}_{t+1}, \\ C_t^M + N_t^M &\leq W_t^M, \\ N_t - N_t^M &\leq (1-\phi_t)(N_t - \Delta_t^*) \\ &\quad + N_t (1-\phi_t) E[M_{t+1}^H \sum_{i \in I} \alpha_t^{i*} (R_{t+1}^i - R_t^b) | z_t], \\ \sum_{i \in I^c} k^i |\alpha_t^i| &\leq 1, \\ N_t^M &\leq N_t. \end{aligned}$$

In defining this problem, we have eliminated the debt level B_t as a choice variable by substituting out the initial budget constraint, and we have assumed that the manager will choose to offer a capital structure acceptable to households. This assumption is without loss of generality, as the manager can always set $N_t^M = N_t$, $\phi_t = 1$, which is equivalent to having her offer rejected. Note also that this problem is part of an equilibrium of the capital raising game. The households expectations Δ_t^* and α_t^{i*} are functions of the proposed capital structure and must be consistent with the manager's ultimate choices given that capital structure.[23]

We next describe a lemma that collects a number of simplifying results, in particular focusing on an equilibrium in which no cashflow diversion occurs in equilibrium and the anticipated asset allocation depends only in the investment opportunities. These results are essentially identical to statements contained in He and Krishnamurthy (2011).

Lemma 2. *In the manager's problem, there exists an equilibrium in which:*

[23]Formally, we do not require that this equilibrium be subgame perfect. This simplification allows us to focus directly on an equilibrium in which the manager puts all her savings in the intermediary. He and Krishnamurthy (2011) Lemma 2 proves (in the context of their model; our model is essentially the discrete time version) that this outcome holds in all equilibria.

1. *The optimal allocation* α_t^{i*} *is a function only of the state vector* z_t*, and satisfies*

$$-1 < E[M_{t+1}^H \sum_{i \in I} \alpha_t^{i*}(R_{t+1}^i - R_t^b)|z_t] < \frac{1}{\psi},$$

2. *There is no diversion,* $\Delta_t = \Delta_t^* = 0$*, and the manager's share satisfies* $\phi_t^* \geq (1+\psi)^{-1}$*,*

3. *The household equity participation constraint binds,*

4. *The manager invests all savings in the intermediary,* $C_t^M + N_t^M = W_t^M$*, with* $N_t^M > 0$*,*

5. *The manager's share* ϕ_t^* *and fee* f_t^M *are functions only of* z_t*, with*

$$f_t^M(z_t) = \frac{\phi_t^*(z_t)}{\phi_t^*(z_t) - (1-\phi_t^*(z_t))E[M_{t+1}^H \sum_{i \in I} \alpha_t^{i*}(R_{t+1}^i - R_t^b)|z_t]}.$$

Proof. See below. □

With these results, the manager's final wealth is

$$\begin{aligned} W_{t+1}^M &= \phi_t \hat{N}_{t+1} \\ &= (W_t^M - C_t^M) f_t^M(\phi_t, z_t)(R_t^b + \sum_{i \in I} \alpha_t^i (R_{t+1}^i - R_t^b)), \end{aligned}$$

and the manager's problem can be written as

$$\begin{aligned} V(W_t^M, z_t) = \max_{C_t^M \geq 0, \{\alpha_t^i\}_{i \in I}} & \frac{(C_t^M)^{1-\gamma}}{1-\gamma} \\ & + \beta E[V(W_{t+1}^M, z_{t+1})|z_t], \end{aligned}$$

subject to

$$W_{t+1}^M = (W_t^M - C_t^M) f_t^M(z_t)(R_t^b + \sum_{i \in I} \alpha_t^i (R_{t+1}^i - R_t^b)),$$

$$\sum_{i \in I^c} k^i |\alpha_t^i| \leq 1,$$

This is the manager's problem defined in the text, equations (2), (3), and (4).

To derive the Euler equation for the wealth portfolio (equation (5)), we combine the first-order condition for consumption with the envelope theorem in the usual way. The first-order condition for α_t^i (equation (6)) also follows immediately.

Consider in particular the first-order conditions associated with a foreign currency risk-free bond and with a forward contract on the exchange rate. The return on the foreign currency bond is $R_t^c \frac{S_t}{S_{t+1}}$, and the profit of the forward (a derivative) is $\frac{S_{t+1}-F_{t,1}}{S_{t+1}}$ per dollar notional. The two first-order conditions are

$$E[\exp(-\gamma \Delta c_{t+1}^M)(R_t^c \frac{S_t}{S_{t+1}} - R_t^b)|z_t] = \lambda_t^{RC} k^c sgn(\alpha_t^c)$$

and

$$E[\exp(-\gamma \Delta c_{t+1}^M)(\frac{S_{t+1} - F_{t,1}}{S_{t+1}})|z_t] = 0.$$

Combining these two equations yields

$$E[\exp(-\gamma \Delta c_{t+1}^M)(R_t^c \frac{S_t}{F_{t,1}} - R_t^b)|z_t] = \lambda_t^{RC} k^c sgn(\alpha_t^c),$$

or

$$E[\exp(-\gamma \Delta c_{t+1}^M)|z_t] R_t^b (\exp(-x_{t,1}) - 1) = \lambda_t^{RC} k^c sgn(\alpha_t^c).$$

Taking absolute values,

$$E[\exp(-\gamma \Delta c_{t+1}^M)|z_t] R_t^b |\exp(-x_{t,1}) - 1| = \lambda_t^{RC} k^c.$$

The remainder of the derivation of Theorem 1 is contained in the text.

C.1 Proof of Lemma 2

First, observe that diversion does not change α_t^{i*} in the conjectured equilibrium. Consequently, the net benefit of stealing is

$$\beta R_t^b E[V_W(W_{t+1}^M, z_{t+1})|z_t](\frac{1}{1+\psi} - \phi_t),$$

and by the usual arguments $V_W(W_{t+1}^M, z_{t+1}) = (C_{t+1}^M)^{-\gamma} > 0$. If $\frac{1}{1+\psi} > \phi_t$, stealing has a net benefit, and this benefit does not diminish. Consequently, there cannot be a solution with outside equity ($N_t^M > N_t$). Conversely, if $\frac{1}{1+\psi} \leq \phi_t$, diversion has a weakly negative net benefit, and it is without loss of generality to suppose diversion does not occur in equilibrium. By the argument in the text, it follows that it is without loss of generality to suppose $\frac{1}{1+\psi} \leq \phi_t$ and there is no equilibrium stealing.

Now consider a perturbation which increases N_t but shrinks α_t^i so that $\alpha_t^i N_t$ remains constant for all assets. If the household participation constraint does not bind, this generates a strict welfare improvement for the manager and is always feasible. Therefore, the household participation constraint binds,

$$\phi_t N_t (1 - \frac{(1-\phi_t)}{\phi_t} E[M_{t+1}^H \sum_{i \in I} \alpha_t^{i*} (R_{t+1}^i - R_t^b)|z_t]) = N_t^M.$$

Note by assumption that

$$-1 < E[M_{t+1}^{H} \sum_{i \in I} \alpha_t^{i*}(R_{t+1}^{i} - R_t^{b})|z_t] < \frac{1}{\psi} \leq \frac{\phi_t}{1-\phi_t}$$

and hence that positive values of N_t^M and N_t are feasible. Observe that if $N_t^M = N_t = 0$, the manager is taking no risk, which cannot be optimal by the principle of participation. Therefore these values are strictly positive.

Under these assumptions, the manager's fee f_t^M is a function of z_t and ϕ_t,

$$f_t^M(\phi_t, z_t) = \frac{\phi_t}{\phi_t - (1-\phi_t)E[M_{t+1}^{H} \sum_{i \in I} \alpha_t^{i*}(R_{t+1}^{i} - R_t^{b})|z_t]},$$

Moreover, the manager's final wealth is

$$W_{t+1}^M = R_t^b(W_t^M - C_t^M - N_t^M) + N_t^M f_t^M(\phi_t, z_t)(R_t^b + \sum_{i \in I} \alpha_t^i(R_{t+1}^i - R_t^b)).$$

Note that $f_t^M(\phi_t, z_t)$ is increasing in ϕ_t if $E[M_{t+1}^{H} \sum_{i \in I} \alpha_t^{i*}(R_{t+1}^{i} - R_t^{b})|z_t] < 0$ and decreasing otherwise. In the increasing case, we must have $\phi_t^* = 1$ and in this case $f_t^M = 1$; in the decreasing case, $f_t^M \geq 1$, and therefore $f_t^M \geq 1$ always. It also follows that ϕ_t^* is purely a function of z_t, and hence the fee f_t^M is also purely a function of z_t.

Now consider a perturbation that increasing N_t^M while scaling down α_t^i so that $N_t^M f_t^M(\phi_t, z_t)\alpha_t^i$ remains constant for all $i \in I$. This perturbation has a weak net benefit, as it increases W_t^M, and hence it is without loss of generality to suppose $N_t^M = W_t^M - C_t^M$.

We have demonstrated the stated properties conditional in the conjectured that α_t^{i*} is a function only of z_t. We now show that this an equilibrium. We scale variables by wealth. Define $c_t^m = \frac{C_t^M}{W_t^M}$. The problem is

$$V(W_t^M, z_t) = \max_{c_t^M \geq 0, \{\alpha_t^i\}_{i \in I}} \frac{(W_t^M)^{1-\gamma}(c_t^M)^{1-\gamma}}{1-\gamma} + \beta E[V(W_{t+1}^M, z_{t+1})|z_t],$$

subject to

$$\frac{W_{t+1}^M}{W_t^M} = f_t^M(z_t)R_t^b(1-c_t^M) + (1-c_t^M)f_t^M(z_t)\sum_{i \in I}\alpha_t^i(R_{t+1}^i - R_t^b),$$

$$\sum_{i \in I^c} k^i|\alpha_t^i| \leq 1.$$

We can immediately conjecture and verify that $V(W_t^M, z_t)$ is homothetic in wealth,

$$V(W_t^M, z_t) = (W_t^M)^{1-\gamma}J(z_t)$$

for some function $J(z_t)$, and that as a result the optimal policies do not depend on wealth (or any capital structure variables), verifying the conjecture.

D Cross-Sectional Asset Pricing Details

In this appendix section, we provide more details about the cross-sectional asset pricing exercise of Section 5. We begin by describing our test asset portfolios, then discuss the differences between our exercise and He et al. (2017) (HKM). Appendix Table A6 shows cross-sectional asset pricing results for our test asset classes with the HKM factors; this table can be compared (noting the differences in asset class definitions and sample) with Table 14 of He et al. (2017).

D.1 Factors and Test Assets

As discussed in the main text, our choice of test assets is inspired by HKM, but constructing the full set tests assets from that paper is work in progress. Below, we describe the data used for each asset class. We truncate all of our series at the end of August 2018.

The Market and the Risk-Free Rate

The equity return we use is the Market factor provided on Ken French's website (originally from CRSP). We also use, for most of our sample, the 1-month t-bill rate provided on Ken French's website (and due to Ibbotson and Associates, Inc.). These are the same data sources used by HKM. However, as discussed on Ken French's website, the Market return was changed in October 2012 and as a result there are some differences between our series and the one originally used by HKM.

We also adjust the risk-free rate in the post-crisis period (as defined in our main text, July 2010 onwards) to use one-month OIS swap rates instead of 1-month t-bill rates. We make this adjustment to be consistent with the risk-free rates we used to compute the cross-currency basis and forward arbitrage returns. The adjustment has a minimal impact on our results.

The HKM Factors

In our equity-return only specification (Table 4), we use as an equity return the "intermediary value-weighted investment return" of HKM, obtained from Asaf Manela's website. When we use the original HKM specification, perhaps augmented with our basis shock (Table 3 and Appendix Table A6), we use our market return described above and the "intermediary capital risk factor" of HKM, obtained from Asaf Manela's website.

Equities (FF)

Our test equity portfolios are the monthly return series of the "25 Portfolios Formed on Size and Book-to-Market" available on Ken French's website, building on Fama and French (1993). This is exactly the same set of test assets used by HKM, who make their full dataset (containing data through 2012) available. The series begins in July 1926. Note that HKM use only the data from 1970 onwards.

There appear to be a variety of small differences between the returns we obtained from Ken French's website in 2018 and the returns HKM obtained in 2012. Many of these differences are small enough that they can be attributed to rounding, but some are not. Ken French's website does mention a variety of changes in CRSP between 2012 and the present, but none seem directly applicable to the 25 size-and-value portfolios.

US Bonds (US)

Our U.S. bond portfolios are the CRSP "Fama Maturity Portfolios" defined in 6-month intervals. To include the returns for a particular month, we require that the returns for all ten maturity buckets be available. As a result, our data starts in February 1971, but has missing months until December 1974. These ten portfolios are half of the twenty US bond portfolios studied by HKM; the remainder are corporate bonds. We intend to collect and include the corporate bond data in the future.

As noted by HKM, treasurys exhibit a strong factor structure, and therefore do not make an ideal test asset class by themselves.

Sovereign Bonds (Sov)

Our sovereign bond portfolio construction follows the procedure of Borri and Verdelhan (2015). Those authors consider all countries in the JP Morgan EMBI index, and sort bonds into six portfolios. They first divide countries into two groups, depending on whether their bonds have a low or high beta to US equity market returns, and then within each of these groups split bonds into three sub-groups based on their S&P rating. HKM use exactly the data of Borri and Verdelhan (2015), as those two papers are roughly contemporaneous.

We implement this procedure with updated data. However, three countries have been dropped from the EMBI index, and do not have returns available for the post-crisis period. These countries are omitted from our entire analysis, and as a result there is an imperfect, but 80% correlation between our portfolio returns and the original Borri and Verdelhan (2015) returns.

Foreign Exchange Portfolios (FX)

We use the 11 forward-premium-sorted portfolios of Lustig et al. (2011). These portfolios consist of between 9 and 34 currencies. Six these portfolios contain all currencies, sorted by forward premia. Five contain only developed-country currencies, sorted by forward premia.

In contrast, HKM use six portfolios sorted by forward premia from Menkhoff et al. (2012) and six portfolios sorted by interest rate differential from Lettau et al. (2014).[24] Because covered interest parity holds for most of the sample, these two groups of portfolios should be essentially identical. However, the two papers differ on data sources and samples (Menkhoff et al. (2012) have up to 48 currencies from 1983 to 2009, Lettau et al. (2014) have up to 53 from 1974 to 2010), and consequently the two sets of portfolios to do not exactly span each other.

OIS and IBOR Forward Arbitrage Returns (OIS FA & IBOR FA)

We use seven the OIS and IBOR forward arbitrage returns in seven currencies (AUD, NZD, CAD, GBP, EUR, CHF, JPY) as test assets. For all of these assets, we study as an excess return

$$x^c_{t,h,\tau} - x^c_{t+h,\tau},$$

which is the profit per dollar notional, normalized by the duration.

We construct the OIS forward arbitrage returns as described in the text. IBOR forward arbitrage returns are constructed in an essentially identical fashion, using 3M spot IBOR rates and FRA agreements with 3M IBOR as the underlying rate. For both sets of arbitrages, we consider only the post-crisis period.

For these asset classes only, we do not require that all returns within the asset class be available to include a month in our sample. For OIS, CHF OIS was reformed in 2017, and therefore we stop our series for CHF only at the end of 2017. For IBOR, the CAD four-month FRA used to construct the forward interest rate is missing for much of 2016-2017.

D.2 Estimation and Standard Errors

Our analysis is the GMM version of a traditional two-pass regression to estimate the price of various risk-factors, as described in chapter 12 of Cochrane (2009). Our point estimate come from an exactly identified single-step GMM estimation procedure, as described on pages 241-243 of Cochrane (2009). We use a Newey-West kernel with those authors' suggested bandwidth-selection procedure (Newey and West (1994)) to construct standard errors that are robust to heteroskedasticity and autocorrelation.

The one key difference between our procedure and the textbook procedure is that we allow the samples for the estimation of the betas and the means to differ. To implement this, we introduce as parameters in our GMM equations a mean-return parameter for each asset and an extra equation for each asset stating that the difference of the mean parameter and the asset excess return is zero in expectation. We then write our cross-sectional asset pricing equation (18) entirely as a function of parameters, with no data. These changes, and allowing our GMM estimator to use different samples for different equations, implement the desired outcome that the mean and beta samples can differ.

[24] The published version of Menkhoff et al. (2012) describes only five portfolios, and two other portfolios that are linear combinations of the five.

E Alternative Carry and Dollar Portfolios

In the international asset pricing literature, Carry and Dollar are two common approaches to forming portfolios. Carry refers to the notion that the portfolio is long in high-interest rate currencies and short in low-interest rate currencies. Dollar refers to the notion that the dollar is the one funding currency for all other currencies. We also define a Carry and a Dollar portfolio in the main text. However, there are several possible ways of constructing Carry and Dollar. In this section, we explore profits and Sharpe ratios of profits from different portfolios of forward CIP trading strategy.

Classic Carry: This portfolio is our Carry portfolio in the main text, where the portfolio profit is defined as the profit from the forward CIP trading strategy profit in the highest interest rate currency (AUD) less that from the lowest interest rate currency (JPY).

2-currency Carry: This portfolio follows the spirit of a "high-minus-low" carry, but we include two high-interest rate currencies and two low-interest rate currencies. Specifically, the portfolio profit is defined as the profit from the forward CIP trading strategy profit in the two currencies that had the highest interest rate in the Pre-Crisis period (AUD, NZD), less that from the two currencies with the lowest interest rate in the Pre-Crisis period (JPY, EUR). Note that while CHF had a lower interest rate than EUR in the Pre-Crisis period, due to unavailability of CHF OIS rates post-2017, we include EUR in the portfolio. The results are largely identical when including CHF instead of EUR.

Dynamic Carry: This portfolio dynamically assigns the portfolio weight to the single-curency profit from forward CIP trading strategy. Weights are determined by each currency's interest rate differential to that of USD. Those with interest rate differentials above the cross-sectional average enters the portfolio as long, and those below the average enters the portfolio as short. The absolute value of the weight is proportional to each currency's interest rate differential.

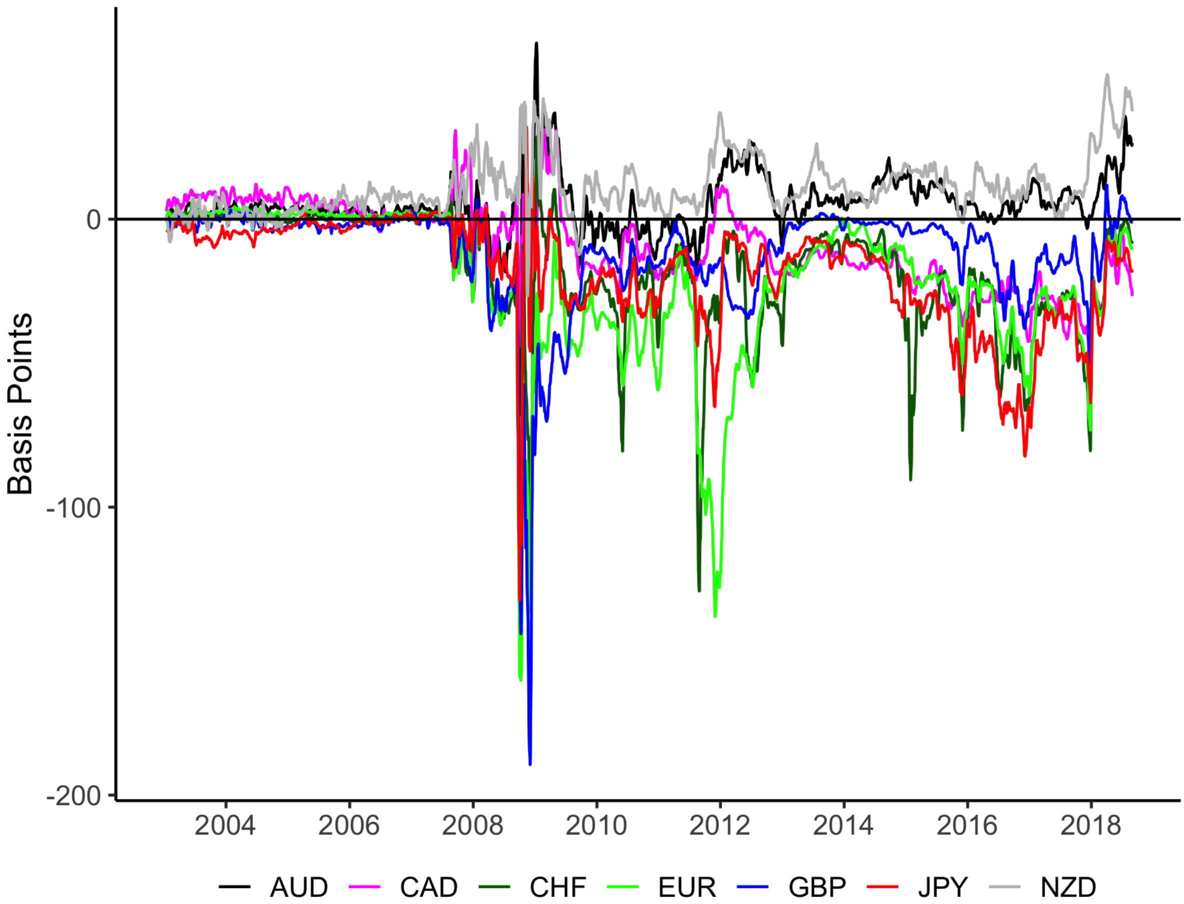
Simple Dollar: This portfolio is our Dollar portfolio in the main text, where the portfolio profit is an equal-weighted average of profits from all the single-currency forward CIP trading strategies.

Carry-neutral Dollar: This portfolio is a linear combination of the Simple Dollar portfolio and the Classic Carry portfolio so that the weighted interest rate differential from all sample currencies relative to the USD is 0. To the extent that interest rate differentials drive the magnitude of CIP violations, this carry-neutral dollar portfolio bears the advantage that the profits are not due to aggregate interest rate differentials in the portfolio.

We present in Table A5 the results of the profits and Sharpe ratios of all these portfolios from following the OIS 1M-forward 3M forward CIP trading strategy. Our main result that the Carry portfolio commands a risk premium while the Dollar portfolio does not, is robust to different definitions of Carry and Dollar.

F Additional Figures and Tables

Figure A1: **Three-month IBOR-based Cross-Currency Bases**



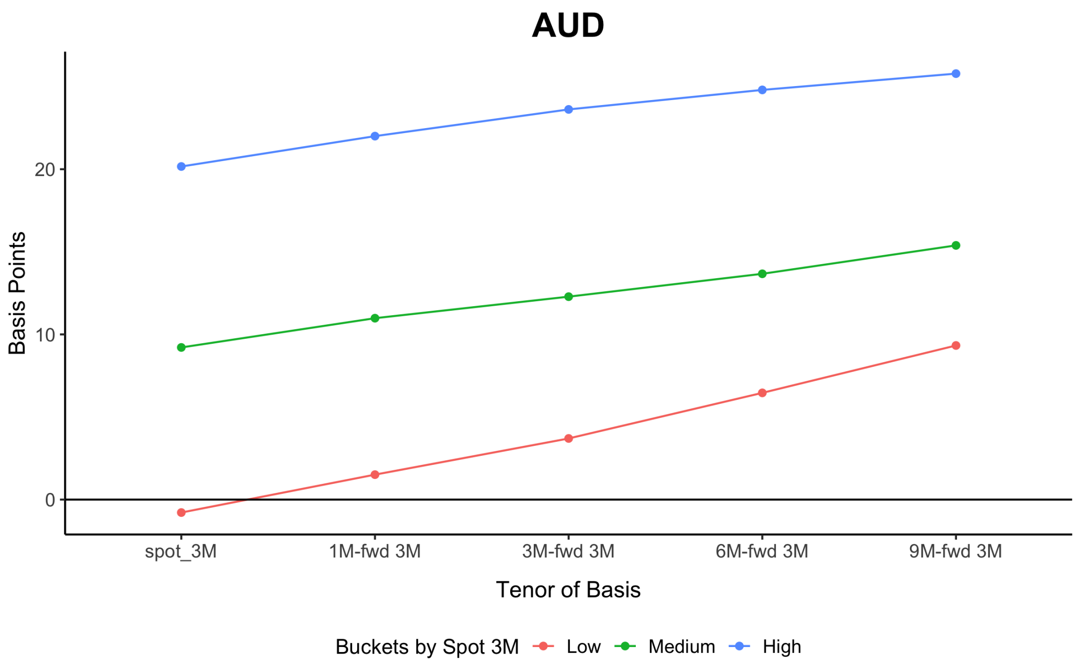
This figure plots the 10-day moving average of daily spot 3M IBOR cross-currency basis, measured in bps, for the seven sample currencies. The spot IBOR basis is $x^c_{t,3}$, as defined in the text.

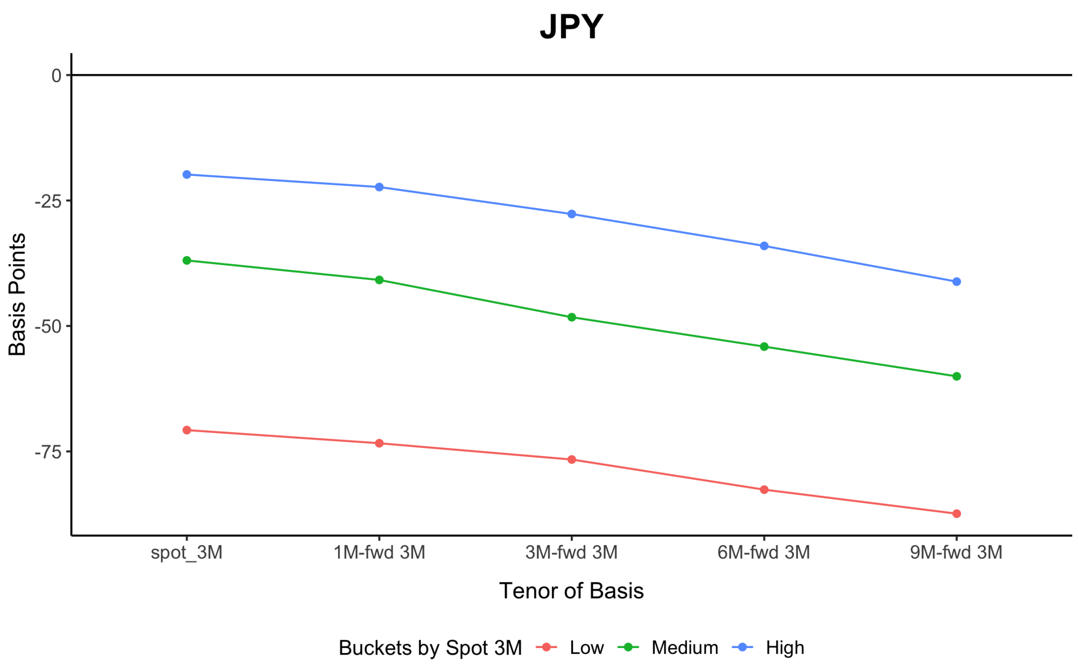
Table A1: **Sample Currencies and the Associated OIS / IBOR Terms**

Panel A: OIS		
Currency	Indexed Rate	Day Count
AUD	Reserve Bank of Australia Interbank Overnight Cash Rate	ACT / 365
CAD	Canadian Overnight Repo Rate Average (CORRA)	ACT / 365
CHF	Tomorrow/Next Overnight Indexed Swaps	ACT / 360
EUR	EMMI Euro Overnight Index Average (EONIA)	ACT / 360
GBP	Sterling Overnight Index Average (SONIA)	ACT / 365
JPY	Bank of Japan Estimate Unsecured Overnight Call Rate	ACT / 365
NZD	Reserve Bank of New Zealand Official Cash Daily Rate	ACT / 365
USD	US Federal Funds Effective Rate	ACT / 360
Panel B: IBOR		
Currency	Interbank Rate	Day Count
AUD	Australia Bank Bill Swap Rate (BBSW)	ACT / 365
CAD	Canada Bankers' Acceptances Rate	ACT / 365
CHF	ICE LIBOR CHF	ACT / 360
EUR	Euribor	ACT / 360
GBP	ICE LIBOR GBP	ACT / 365
JPY	ICE LIBOR JPY	ACT / 360
NZD	New Zealand Bank Bill Rate	ACT / 365
USD	ICE LIBOR USD	ACT / 360

This table reports the Overnight Index Swap terms and IBOR terms for sample currencies and the U.S. dollar. The Overnight Rate refers to the reference rate used to calculate the interest on the floating leg, against the expectation of which, the rate on the fixed leg is determined. The Day Count specifies how interests are calculated from the quoted annualized rate. For example, with a quoted annualized rate of 2%, a 32-day contract with a day count of ACT/360 would earn an interest of $(1 + 0.02 \times 32/360) - 1$.

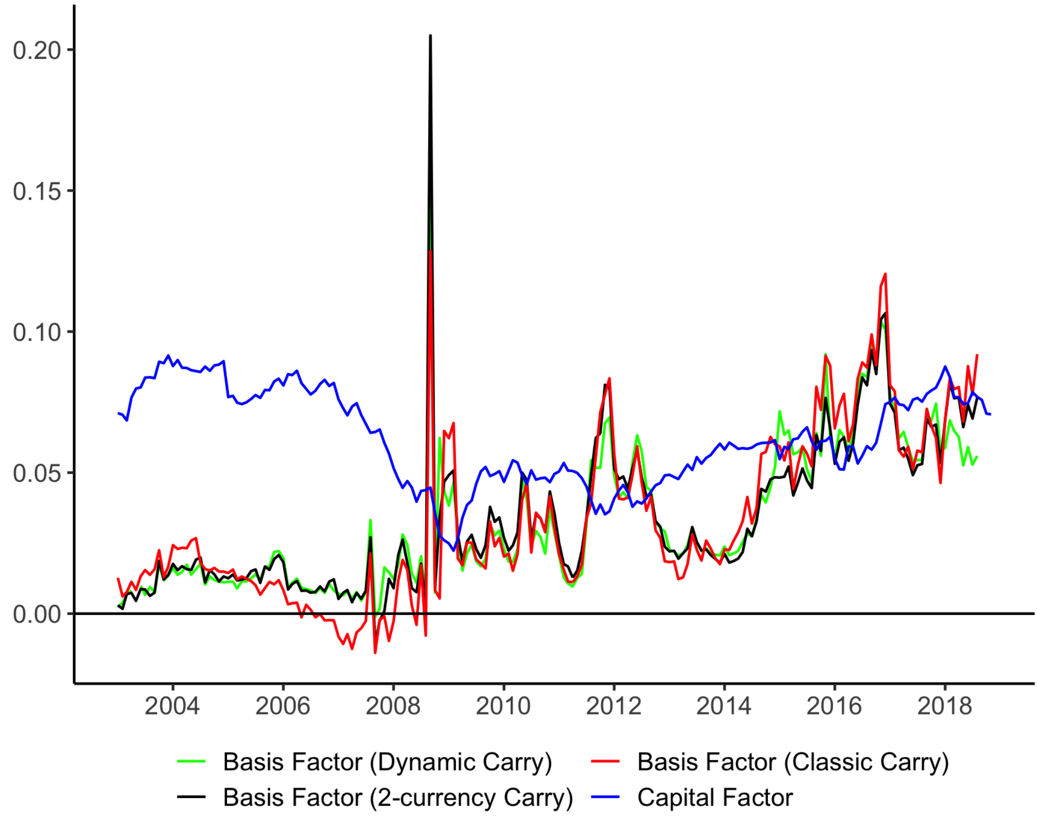
Figure A2: **Term structure of the forward cross-currency basis (alternative forward tenors)**





This figure illustrates the time series average spot and forward-starting cross-currency bases in AUD and JPY. For each currency, the sample from July 2010 to August 2018 is split into three sub-samples based on the tercile of the level of the spot 3M OIS cross-currency basis. Within each sub-sample, the time series average of the relevant spot/forward OIS cross-currency basis is shown. Compared to Figure 3, this Figure plots a different set of forward tenors.

Figure A3: **Variations of the Basis Factor vs. HKM Capital Factor**



This figure plots the monthly basis factor and HKM capital factor from 2003 to August 2018. The three versions of the basis factor plotted are all based on the spot 3M OIS basis and scaled by 10. Dynamic carry weighs all 7 cross-currency forward arbitrage profits based on each currency's OIS-spread to USD. Classic carry longs AUD and shorts JPY forward arbitrage. 2-currency Carry longs AUD and NZD, and shorts JPY and EUR forward arbitrage. The HKM capital factor is the intermediary capital ratio.

Table A2: **Summary Statistics of Returns on OIS 3M-forward 3M Forward CIP Trading Strategy**

Panel A: Single Currencies						
	Mean			Sharpe Ratio		
	Pre-Crisis	Crisis	Post-Crisis	Pre-Crisis	Crisis	Post-Crisis
AUD	3.94	21.50	7.89*	0.29	0.27	0.48
	(2.83)	(23.58)	(3.90)	(0.18)	(0.29)	(0.25)
CAD	0.32	28.42	11.81***	0.03	0.42	0.87***
	(1.98)	(20.72)	(3.02)	(0.21)	(0.28)	(0.24)
CHF	2.44	10.95	-6.49	0.17	0.14	-0.17
	(3.01)	(23.45)	(8.80)	(0.18)	(0.28)	(0.25)
EUR	-0.56	19.24	-2.67	-0.07	0.24	-0.12
	(1.73)	(24.45)	(5.13)	(0.21)	(0.27)	(0.23)
GBP	-1.96	22.18	10.47***	-0.25	0.33	0.77***
	(1.24)	(19.54)	(2.94)	(0.16)	(0.25)	(0.22)
JPY	1.94	19.12	-22.05***	0.13	0.22	-0.82***
	(4.15)	(25.88)	(6.19)	(0.24)	(0.26)	(0.22)
NZD	-13.35***	3.18	0.79	-0.83**	0.05	0.07
	(3.51)	(18.40)	(2.49)	(0.32)	(0.29)	(0.22)

Panel B: Portfolios						
	Mean			Sharpe Ratio		
	Pre-Crisis	Crisis	Post-Crisis	Pre-Crisis	Crisis	Post-Crisis
Carry	1.85	2.22	29.96***	0.15	0.05	1.04***
	(2.56)	(8.97)	(6.67)	(0.22)	(0.20)	(0.26)
Dollar	2.50	18.00	0.05	0.21	0.26	0.00
	(3.80)	(21.49)	(3.35)	(0.27)	(0.28)	(0.23)

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table reports the annual profits and annualized Sharpe ratios from the OIS 3M-forward 3M forward CIP trading strategy. All statistics are reported by period: Pre-Crisis is 2003-01-01 to 2007-06-30, Crisis is 2007-07-01 to 2010-06-30, and Post-Crisis is 2010-07-01 to 2018-08-31. Panel A reports results in single currencies. Panel B reports results in portfolios of single currency forward CIP trading strategy. The Carry portfolio is formed by longing the AUD and shorting the JPY forward CIP trading strategy. The Dollar portfolio is formed by going long in all seven sample currencies' forward CIP trading strategy in equal weight. Newey-West standard errors are reported in parenthesis, where the overlapping bandwidth is chosen by the Newey-West (1994) selection procedure.

Table A3: **Summary Statistics of Returns on IBOR 1M-forward 3M Forward CIP Trading Strategy**

Panel A: Single Currencies						
	Mean			Sharpe Ratio		
	Pre-Crisis	Crisis	Post-Crisis	Pre-Crisis	Crisis	Post-Crisis
AUD	2.12*	-18.81*	6.92***	0.55	-0.72*	1.33***
	(1.08)	(9.41)	(1.40)	(0.28)	(0.30)	(0.27)
CAD	2.87*	-8.59	10.54***	0.68*	-0.44	2.20***
	(1.21)	(8.29)	(1.71)	(0.31)	(0.39)	(0.47)
CHF	-2.76***	2.58	-1.77	-0.91***	0.10	-0.13
	(0.77)	(10.02)	(4.12)	(0.26)	(0.39)	(0.31)
EUR	0.43	21.08*	3.18	0.15	0.87**	0.32
	(0.53)	(10.22)	(3.38)	(0.19)	(0.30)	(0.32)
GBP	0.31	13.38	4.78**	0.08	0.58	0.93**
	(1.17)	(9.50)	(1.57)	(0.29)	(0.36)	(0.33)
JPY	-2.22*	-5.56	-7.74**	-0.80*	-0.19	-0.94***
	(1.07)	(11.53)	(2.47)	(0.39)	(0.41)	(0.28)
NZD	5.84**	-23.08**	3.51	0.66**	-1.24***	0.52
	(1.86)	(7.90)	(2.29)	(0.25)	(0.31)	(0.32)

Panel B: Portfolios						
	Mean			Sharpe Ratio		
	Pre-Crisis	Crisis	Post-Crisis	Pre-Crisis	Crisis	Post-Crisis
Carry	4.60***	-12.56	14.67***	1.09***	-0.47	1.58***
	(1.38)	(9.54)	(2.71)	(0.31)	(0.34)	(0.29)
Dollar	0.54	-2.31	2.30	0.27	-0.14	0.48
	(0.60)	(7.36)	(1.52)	(0.31)	(0.44)	(0.30)

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table reports the annual profits and annualized Sharpe ratios from the IBOR 1M-forward 3M forward CIP trading strategy. All statistics are reported by period: Pre-Crisis is 2003-01-01 to 2007-06-30, Crisis is 2007-07-01 to 2010-06-30, and Post-Crisis is 2010-07-01 to 2018-08-31. Panel A reports results in single currencies. Panel B reports results in portfolios of single currency forward CIP trading strategy. The Carry portfolio is formed by longing the AUD and shorting the JPY forward CIP trading strategy. The Dollar portfolio is formed by going long in all seven sample currencies' forward CIP trading strategy in equal weight. Newey-West standard errors are reported in parenthesis, where the overlapping bandwidth is chosen by the Newey-West (1994) selection procedure.

Table A4: **Summary Statistics of Returns on IBOR 3M-forward 3M Forward CIP Trading Strategy**

Panel A: Single Currencies						
	Mean			Sharpe Ratio		
	Pre-Crisis	Crisis	Post-Crisis	Pre-Crisis	Crisis	Post-Crisis
AUD	5.02***	-4.92	11.29***	0.73***	-0.11	0.88***
	(0.89)	(9.82)	(2.81)	(0.15)	(0.20)	(0.25)
CAD	3.08*	22.02*	22.31***	0.36*	0.60	1.72***
	(1.48)	(9.79)	(2.95)	(0.16)	(0.32)	(0.29)
CHF	-1.49	7.83	-5.72	-0.26	0.17	-0.18
	(0.93)	(12.50)	(6.74)	(0.19)	(0.27)	(0.23)
EUR	0.78	34.58**	3.31	0.14	0.73**	0.11
	(0.98)	(12.78)	(7.15)	(0.15)	(0.24)	(0.23)
GBP	1.70	30.69*	9.39**	0.20	0.63***	0.71***
	(1.49)	(13.42)	(2.89)	(0.17)	(0.17)	(0.21)
JPY	-0.39	-1.93	-19.91***	-0.06	-0.05	-0.98***
	(1.26)	(9.84)	(4.51)	(0.19)	(0.24)	(0.23)
NZD	1.63	-30.77***	3.58	0.10	-0.90***	0.23
	(2.17)	(9.11)	(3.48)	(0.13)	(0.20)	(0.23)

Panel B: Portfolios						
	Mean			Sharpe Ratio		
	Pre-Crisis	Crisis	Post-Crisis	Pre-Crisis	Crisis	Post-Crisis
Carry	4.83**	-3.05	31.20***	0.53***	-0.07	1.43***
	(1.74)	(6.60)	(4.77)	(0.15)	(0.15)	(0.29)
Dollar	0.89	8.68	3.45	0.24	0.28	0.27
	(0.55)	(8.53)	(2.88)	(0.14)	(0.28)	(0.22)

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table reports the annual profits and annualized Sharpe ratios from the IBOR 3M-forward 3M forward CIP trading strategy. All statistics are reported by period: Pre-Crisis is 2003-01-01 to 2007-06-30, Crisis is 2007-07-01 to 2010-06-30, and Post-Crisis is 2010-07-01 to 2018-08-31. Panel A reports results in single currencies. Panel B reports results in portfolios of single currency forward CIP trading strategy. The Carry portfolio is formed by longing the AUD and shorting the JPY forward CIP trading strategy. The Dollar portfolio is formed by going long in all seven sample currencies' forward CIP trading strategy in equal weight. Newey-West standard errors are reported in parenthesis, where the overlapping bandwidth is chosen by the Newey-West (1994) selection procedure.

Table A5: **Summary Statistics of Alternative Portfolio Profits on OIS 1M-forward 3M Forward CIP Trading Strategy**

	Mean			Sharpe Ratio		
	Pre-Crisis	Crisis	Post-Crisis	Pre-Crisis	Crisis	Post-Crisis
Classic Carry	2.44	-4.37	14.25***	0.61	-0.16	1.38***
	(1.34)	(10.79)	(3.26)	(0.34)	(0.38)	(0.33)
2-currency Carry	-1.77	-9.87	8.01**	-0.43	-0.37	0.96**
	(1.07)	(11.22)	(2.72)	(0.25)	(0.38)	(0.35)
Dynamic Carry	-1.15	-6.89	6.19*	-0.28	-0.31	0.75*
	(1.17)	(9.23)	(2.72)	(0.28)	(0.39)	(0.37)
Simple Dollar	-1.46	6.16	0.07	-0.68*	0.18	0.02
	(0.77)	(16.53)	(1.52)	(0.34)	(0.44)	(0.33)
Carry-neutral Dollar	-1.52	7.46	-1.13	-0.63	0.18	-0.20
	(0.91)	(18.61)	(1.84)	(0.35)	(0.43)	(0.32)

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table reports the annual profits and annualized Sharpe ratios from portfolios of OIS 1M-forward 3M forward CIP trading strategy. All statistics are reported by period: Pre-Crisis is 2003-01-01 to 2007-06-30, Crisis is 2007-07-01 to 2010-06-30, and Post-Crisis is 2010-07-01 to 2018-08-31. The Carry portfolio is formed by going long the AUD forward CIP trading strategy and short the JPY forward CIP trading strategy. The 2-currency Carry portfolio is formed by longing AUD and NZD, and shorting JPY and EUR forward CIP trading strategy. The Dynamic Carry portfolio weighs all 7 cross-currency forward CIP trading strategy profits based on each currency's OIS-spread to USD. The Simple Dollar portfolio longs all seven sample currencies' forward CIP trading strategy with equal weight. The Carry-neutral dollar portfolio linearly combines Classic Carry and Simple Dollar to achieve a zero interest-rate differential relative to USD. Newey-West standard errors are reported in parenthesis, where the overlapping bandwidth is chosen by the Newey-West (1994) selection procedure.

Table A6: **Cross-sectional Asset Pricing Tests, HKM Factors.**

	(1) US	(2) Sov	(3) FX	(4) FF	(5) US/Sov/FX	(6) OIS-FA	(7) IBOR-FA
Market	-2.652***	0.0839	2.231***	0.228	1.000***	-3.817***	-6.330***
	(0.296)	(0.352)	(0.433)	(0.864)	(0.165)	(0.471)	(0.572)
HKM Factor	-2.417***	2.400*	3.292**	1.316	0.0462	1.606***	0.871***
	(0.336)	(1.214)	(1.107)	(2.248)	(0.627)	(0.157)	(0.264)
Intercepts	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MAPE (N (assets)	10	6	11	25	27	7	7
N (beta, mos.)	224	283	418	584		98	98
N (mean, mos.)	224	283	418	1106		98	98

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: This table reports cross-sectional asset pricing tests for various asset classes. Mkt and HKM factor and two factors employed by He et al. (2017). Intercepts indicates an intercept is used for each asset class (one intercept per column, with 3 in column 5). MAPE is mean absolute pricing error of monthly returns. The asset classes are described in Appendix Section D. Standard errors are computed using GMM with the Newey-West kernel and bandwidth selection procedure (Newey and West (1994)). Units are in percentage points.