Intertemporal Risk in the Foreign Currency Futures Basis

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Abstract
We investigate covariation of payoffs from spot and futures positions in foreign currency markets. The weights in a hedged position are determined by the prices of futures and spot contracts and by foreign and domestic interest rates. Evaluating this hedged position using an intertemporal asset-pricing model leads to a testable equilibrium model for the time series evolution of the futures basis. Systematic intertemporal risk will be proportional to the conditional covariance of the basis with a generalized discount factor. Empirical implementation uses a conditional capital-asset-pricing model (CAPM) in which both the quantity and the price of covariance risk are free to vary over time. However, for this application, the estimated intertemporal risk is insignificantly different from zero, the risk in the futures position offsets that in the spot, providing an effective hedge.

Résumé
La covariance des recettes découlant des positions à terme et au comptant prises sur les marchés des devises constitue l'objet principal de cette étude. Les pondérations utilisées pour la position couverte sont fixées à partir des prix des contrats à terme et des contrats au comptant d'une part et à partir des taux d'intérêt étranger et national de l'autre. La position couverte ainsi définie peut alors être évaluée à l'aide d'un modèle temporel d'évaluation des actifs financiers. Ceci rend possible la formualtion d'un modèle d'équilibre de l'évolution de la série temporelle de la « base » (basis) sur le marché à terme vérifiable empiriquement. Dans cette formulation, le risque systématique temporel est proportionnel à la covariance conditionnelle de la base ajustée à l'aide d'un facteur d'actualisation généralisé. La vérification empirique de ce modèle utilise un modèle conditionnel d'évaluation des actifs financiers dans lequel le prix ainsi que l'amplitude du risque de covariance peuvent varier librement sur le temps. Cependant, dans cette application, le risque temporel estimé n'est pas significativement différent de zéro, le risque de la position à terme étant contrebalancé par celui de la position au comptant dans le contexte d'une couverture parfaite.

The basis of or difference between futures and spot prices at a given time t plays a central role in most theories of hedging using futures markets. For example, being able to translate a futures price into a price for delivery of the underlying security (spot price) is essential for deciding whether and when to hedge.

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Working (1953) regarded hedging not as a form of insurance but as a sort of speculation undertaken in the context of anticipating a change in the basis over the life of the futures contract. In his view, hedging involves the purchase or sale of futures along with another commitment in the spot market, in anticipation of a favourable change in the basis.[1] For example, a hedger who believes the futures price to be too high relative to the current spot price borrows cash to buy the spot commodity and takes a short position in the futures market, contracting to deliver the commodity at a later date. Conversely, a hedger who believes the futures price to be too low relative to the spot price takes a long position in the futures

This model allows us to test directly for intertemporal risk associated with the hedged position. Then, specifying a trivariate system for each currency allows us to estimate an unrestricted model and test various restrictions implied by the capital-asset-pricing model (CAPM) and the intertemporal risk hypothesis.

In the fourth section we present the results. These include parameter estimates for the basis model as well as residual-based diagnostic tests and tests for misspecification of that model. Results for tests of restrictions related to systematic intertemporal risk are also presented. Finally, using the unrestricted trivariate specification of the separate components of the basis position, results are presented for some restrictions implicit in the bivariate specification. The final section is the conclusion.

Theoretical Framework

Equilibrium Valuation for the Basis in Foreign Currency Markets

In this section, we characterize the time series evolution of the basis in terms of the present value of a hedged position in which a long commitment in the spot is offset by an appropriately chosen short position in the futures. The equilibrium valuation expression for the basis includes compensation for intertemporal risk as a function of the conditional covariance of the value of the position with the generalized discount variable or intertemporal marginal rate of substitution of domestic currency. Naturally, the amount of risk will depend on the particular hedge ratio chosen, and there are situations in which the intertemporal risk reduces to zero.

All prices are expressed in terms of units of domestic currency and the interest rates are nominal. Let

- C_t = the number of units of the single consumption good consumed at t;
- P_t = the price per unit of the (consumption) good at t;
- F_t = the futures price at t for a contract which expires at T;
- S_t = the spot price for the underlying commodity;
- R_t = 1 plus the domestic rate of interest from t to $t + 1$;
- Z_t = 1 plus the foreign interest rate from t to $t + 1$;
- M_t = the generalized discount or nominal benchmark variable for the period t - 1 to t.

With the assumption of complete markets, the no-arbitrage condition uniquely defines a positive generalized discount or nominal benchmark variable M_t for equilibrium asset pricing. For example, a $1 investment in a one-period domestic bond has a payoff of R_{t-1} for which the present value must be $1, that is,

$$1 = \mathrm{E}_{t-1}[M_t R_{t-1}]. \tag{1}$$

Asset-pricing models specify the nominal benchmark variable M_t in different ways. For example, in utility-based valuation theories, Equation 1 is a particular application of the fundamental valuation equation that equates the price of a claim to the expected product of the future payoff and the marginal rate of substitution of the representative investor (Constantinides, 1989). In particular, with nominal payoffs, M_t can be interpreted as the intertemporal marginal rate of substitution of domestic currency. For example, for the special case of a time-additive utility function with a constant time discount factor ρ,

$$M_t \equiv \rho \frac{u'_t}{u'_{t-1}} \frac{P_{t-1}}{P_t} \equiv m_t \frac{P_{t-1}}{P_t}, \tag{2}$$

in which u'_t is the marginal utility of consumption and P_{t-1} / P_t reflects the change in the purchasing power of domestic currency.

We discuss various alternative proxies for the nominal benchmark variable M_t when discussing empirical implementation. At this point, it is sufficient to use M_t in conjunction with E_{t-1}, the conditional expectations operator, as a present value operator (Richard & Sundaresan, 1981) to convert equilibrium nominal payoffs at t to present values at t - 1. We proceed to do this for the payoffs associated with a hedged position in a foreign currency.

A long position in the spot commodity and a short position in futures can be established at zero investment outlay. The fact that the present value of this position is zero leads directly to a testable equation for the basis.

Consider borrowing domestically to buy one unit of foreign currency to be invested in a one-period foreign bond or Eurocurrency deposit. That is, buy one unit of foreign currency in the spot market for S_{t-1}, borrowing at the domestic rate R_{t-1} - 1 to do so, and invest the unit at the foreign rate Z_{t-1} - 1. At the same time, go short q futures contracts for that currency. At time t - 1 there is no net investment outlay for these transactions while the payoff at time t is:

$$Z_{t-1}S_t - R_{t-1}S_{t-1} - q(F_t - F_{t-1}). \tag{3}$$

That is, at t, receive Z_{t-1} units of spot and sell them for their value $Z_{t-1}S_t$; repay the loan plus interest for a total of $R_{t-1}S_{t-1}$; receive a cash flow of $-q(F_t - F_{t-1})$ from the short position in futures; and cancel the futures market position by going long q contracts.

market and a short position in the spot market by borrowing the commodity and selling it with a commitment to return it to the lender later. In these two strategies, the anticipated gains are most easily understood in the special cases of a positive basis at the time the first strategy is initiated and a negative basis for the second: the hedger gains as the basis approaches zero with convergence of the futures and spot prices towards the end of the life of the futures contract.

What these two strategies ignore is intertemporal risk. Since futures and spot prices do not necessarily move together as anticipated, the basis may change in an unfavourable direction. Even if offsetting commitments in the futures and spot markets are frequently adjusted,[2] the value of the hedged position fluctuates, and if the position is not maintained until the expiration of the futures contract, the hedger may realize a loss.

Stein (1961) treated hedging as an expected utility maximization problem involving the mean and variance of the gains from storage in a partially hedged position over the life of the futures contract. Johnson (1960) solved for the minimum variance combination of spot and futures as components of a hedge portfolio, and Ederington (1979) applied this analysis to several financial futures markets. In these analyses, the implicit measure of risk is the minimum value of the variance. However, such risk could be diversifiable. According to equilibrium asset-pricing models, it is nondiversifiable (systematic) risk that is priced.

Stoll (1979) developed an expression for the basis in a one-period model. The single period implies that interest rates will be deterministic, so that futures and forward prices will be identical. As Black (1976) and Jarrow and Oldfield (1981) emphasized, it is important to distinguish between futures contracts and forward contracts. The groundwork for a testable equilibrium model specifically for the basis in futures markets was laid by Cox, Ingersoll, and Ross (1981), who characterized the basis for a rentable commodity at time t in terms of a specific stream of random payments starting at $t + 1$ and ending at the expiration of the futures contract.

Much of the earlier empirical literature has dealt with commodities and related the basis to factors such as cost-of-carry (time value of money or storage costs), convenience yield, and asymmetric information.[3] For example, Fama and French (1987) found that the basis for various commodities is related to the time-to-expiration interest rate and monthly seasonal indicators. They also proposed an alternative decomposition in which the basis equals the expected change in the spot price over the remaining time to expiration plus an expected premium if the futures price differs from the expected future spot price. Bailey and Chan (1993) and Baum and Barkoulas (1996) interpreted this expected premium as an ex ante risk premium and explored whether observed proxies for risk premiums in stock and bond markets (dividend yields and corporate bond spreads) are related to common basis variability across different commodity and foreign currency markets, respectively.

Empirical work analyzing dynamics of the basis associated with common stock index futures has focused on market microstructure issues[4] such as bid-ask spreads, stale prices in the stock index, and the price-discovery role of futures markets. Figlewski (1984) discussed sources of basis risk in common stock index futures and estimated a regression equation in which the dependent variable was the day-to-day change in the basis, and the explanatory variables were the change in the spot value and the basis calculated as though the position were held to expiration of the contract. Beaulieu (1998) adapted the model for intertemporal risk proposed in our paper to stock indices.

Our objective in this paper is to derive a testable equilibrium model for the time series evolution of the basis and to apply it to foreign currency markets. In the next section, we design a hedged position involving futures and spot contracts with weights determined by their prices and by foreign and domestic interest rates. Evaluating this hedged position with an intertemporal asset-pricing model (IAPM) leads to a testable equilibrium model for the intertemporal evolution of the foreign currency futures basis. Intertemporal risk in our model is the conditional covariance of the basis with a generalized discount factor. This contrasts with analyses in which the aim has been to find the minimum variance portfolio constructed from the futures and the underlying spot commodity, in isolation from other available investment opportunities. In other words, our model prices nondiversifiable or systematic intertemporal risk associated with the basis.

The third section explains the test equations and their testable restrictions. Our empirical implementation involves joint quasi-maximum likelihood (QML) estimation of the first and second conditional moments of a system consisting of the payoffs to a futures market position, together with excess returns on a spot position and on a benchmark portfolio. The benchmark portfolio represents international wealth, consistent with the conditional capital-asset-pricing version of the IAPM. We use a multivariate, potentially asymmetric, generalized ARCH process to parameterize the evolution of the conditional second moments, allowing both the quantity and the price of covariance risk to vary over time.

We begin with a bivariate model that evaluates the joint time series evolution of the excess returns associated with the hedged or basis position (excess returns on a spot position together with payoffs to a futures market position) and excess returns on the benchmark portfolio.

The hedged position with the time t payoff indicated in Equation 3 must have a present value of zero at time t - 1 since the outlay at t - 1 is zero, so that:

$$E_{t-1}[M_t(Z_{t-1}S_t - R_{t-1}S_{t-1} - q(F_t-F_{t-1}))] = 0, \quad (4)$$

which, using Equation 1 and the definition of conditional covariance, can be reexpressed as:

$$\frac{q}{R_{t-1}}F_{t-1} - S_{t-1} = \frac{1}{R_{t-1}}E_{t-1}[q(F_t-Z_{t-1}S_t] + cov_{t-1}[M_t,qF_t-Z_{t-1}S_t]. \quad (5)$$

The covariance risk of this hedged position is $cov_{t-1}[M_t,qF_t-Z_{t-1}S_t]$. For illustrative purposes, if we assume that the risk associated with a position in the futures market is proportional to that associated with the underlying cash commodity (note that nothing in our implementation requires that this be the case),

$$cov_{t-1}[M_t,F_t] = k\ cov_{t-1}[M_t,S_t], \quad (6)$$

we can reexpress the covariance risk of the hedged position as:

$$cov_{t-1}[M_t,qF_t-Z_{t-1}S_t] = (kq-Z_{t-1})\ cov_{t-1}[M_t,S_t]. \quad (7)$$

If we knew k, we could choose a hedge ratio q to give zero risk. For given k, other choices of q would lead to either positive or negative intertemporal risk. For example, going short $q=Z_{t-1}$ units of futures leads to an expression for the expected basis,

$$F_{t-1} - \frac{R_{t-1}}{Z_{t-1}}S_{t-1} = E_{t-1}[F_t-S_t] + R_{t-1}\ cov_{t-1}[M_t,F_t-S_t]. \quad (8)$$

The second term on the right side of Equation 8 is the risk for this particular hedged position and, from Equation 7, it can be rewritten as $(k\text{-}1)Z_{t-1}cov_{t-1}[M_t,S_t]$, which is zero if $k = 1$.

A different choice of hedge ratio, $q = R_{t-1}$, leads to an expression for the basis at t - 1,

$$F_{t-1} - S_{t-1} = E_{t-1}\left[F_t - \frac{Z_{t-1}}{R_{t-1}}S_t\right] + cov_{t-1}[M_t,R_{t-1}F_t-Z_{t-1}S_t]. \quad (9)$$

The covariance risk of this position can be rewritten as $(kR_{t-1}\text{-}Z_{t-1})\ cov_{t-1}[M_t,S_t]$, which is zero if $k = Z_{t-1}/R_{t-1}$.

The conditional covariance of a payoff with the nominal benchmark variable M_t is a general measure of intertemporal risk. As indicated in Equation 2, in a utility-based model M_t will be a function of marginal utility. In this case we can interpret nonzero risk in terms of the relative covariation of F_t and S_t with the marginal utility of consumption. For the sake of simpler exposition, let $E_{t-1}(F_t-S_t)$ be zero. Then the left side of Equation 8, $F_{t-1} - S_{t-1}R_{t-1}/Z_{t-1}$, has the same sign as that of $cov_{t-1}[M_t,F_t-S_t]$. Suppose that the marginal utility of consumption is declining in C_t. It follows that $F_{t-1} > S_{t-1}R_{t-1}/Z_{t-1}$ if futures contracts are a better hedge against variation in consumption at t than are spot contracts, or, equivalently, that $cov_{t-1}[M_t,F_t]>cov_{t-1}[M_t,S_t]$. However, if the spot is the better hedge against variation in consumption at t, then $F_{t-1}<S_{t-1}R_{t-1}/Z_{t-1}$. Given that Equation 8 is based on a hedge ratio of $q = Z_{t-1}$, a sufficient condition for the conditional covariance term in Equation 8 to be zero is that the futures price and the spot price have the same covariation with the marginal utility from a dollar's worth of consumption, that is, $k = 1$ in Equations 6 or 7.

Recall that, since the contracts pay off in money, we have defined the benchmark variable M_t in nominal terms. An assumption of risk neutrality is not sufficient to guarantee a zero covariance term in Equation 8, since M_t, as defined in Equation 2, is the product of two random variables, m_t and P_t. A further decomposition could be used to separate the conditional covariance in Equation 8 into two conditional covariances, one reflecting purchasing power risk and the other reflecting the covariation between a real benchmark variable and the real basis.

Scaling Equation 8 by S_{t-1} and rearranging gives

$$E_{t-1}\left[\frac{F_t-S_t}{S_{t-1}}\right] - \left[\frac{F_{t-1}}{S_{t-1}} - \frac{R_{t-1}}{Z_{t-1}}\right] = -\frac{R_{t-1}}{S_{t-1}}cov_{t-1}[M_t,F_t-S_t]. \quad (10)$$

that is, the adjusted change in the basis is expected to be proportional to the intertemporal risk associated with the hedged position.

Empirical Specification of the Benchmark Variable M_t

Alternative asset-pricing models specialize the fundamental valuation equation by their particular specification of the generalized discount or benchmark variable M_t. The intertemporal asset-pricing model hypothesizes that a vector of states is a sufficient statistic for determining marginal utility (Merton, 1973), whereas the consumption-based asset-pricing model shows that the single-state variable, aggregate consumption, may be adequate (Breeden, 1979). The one-period CAPM uses aggregate wealth or the market return as the single-state variable (Black, 1976; Dusak, 1973).

Analyses of futures prices favour the use of daily data because of interest rate risk associated with marking to market. We use a conditional capital asset-pricing representation of Equation 10 for empirical implementation. Following Hansen and Richard (1987), we express our conditional beta asset-pricing relation in terms of a benchmark portfolio hypothesized to be on the conditional mean variance frontier. For example, if there exists an asset or portfolio return R_m perfectly conditionally correlated with M_t, then a portfolio giving returns R_B that are a linear combination of R_m and the risk-free return will be conditionally mean-variance efficient. The equilibrium expected return on any asset then depends on its conditional beta with that benchmark portfolio and we can reexpress Equation 10 as the single-beta conditional capital-asset-pricing relation,

$$E_{t-1}\left[\frac{F_t-S_t}{S_{t-1}}\right]-\left[\frac{F_{t-1}}{S_{t-1}}-\frac{R_{t-1}}{Z_{t-1}}\right]= cov_{t-1}[F_t-S_t,R_{B\,t}]\,\frac{E_{t-1}[R_{B\,t}-R_{t-1}]}{var_{t-1}[R_{B\,t}]}. \qquad (11)$$

Several approaches to measuring such a benchmark portfolio have been proposed. One can treat the benchmark portfolio as unobservable (e.g., Campbell & Hamao, 1992) and use either a latent variable approach or factor representing portfolios to estimate the benchmark portfolio returns. Breeden, Gibbons, and Litzenberger (1989) proceeded by constructing a portfolio with returns maximally correlated with the growth rate of consumption. McCurdy and Morgan (1992a) used benchmark portfolios for both consumption (a maximum correlation portfolio) and wealth (a world equity portfolio) in an empirical implementation motivated by nonexpected utility explanations of asset prices.

In this paper, we use the return on the Morgan Stanley Capital International (MSCI) world equity index as the benchmark portfolio return, replacing R_B in Equation 11 by the world equity return, R_W. Choosing an observable index, as do Harvey (1991) and Mark (1988), is open to the Roll critique (1977). Nevertheless, the MSCI world index represents extensive international diversification.

The relevance of global wealth for pricing risk presumes integrated markets. Campbell and Hamao (1992), Chan, Karolyi, and Stulz (1992), DeSantis and Gerard (1997), and Dumas and Solnik (1995) among others, provided some empirical evidence that supports this hypothesis for the markets relevant to this study. The issue of whether this choice for the benchmark portfolio, in the single-beta formulation (Equation 11) of the conditional pricing relation (Equation 10), is adequate to price all of the relevant risk associated with foreign currency spot and futures prices has also been addressed (without tests of cross-equation restrictions) in McCurdy and Morgan (1991, 1992b).

Test Equations

Test Equation System for the Time-Series Evolution of the Basis

We define the adjusted change in the basis, or scaled payoff, to be

$$y_{bt}=\frac{F_t-S_t}{S_{t-1}}-\left[\frac{F_{t-1}}{S_{t-1}}-\frac{R_{t-1}}{Z_{t-1}}\right] \qquad (12)$$

and the excess return on the world equity benchmark portfolio as $R^*_{wt} = R_{wt} - R_{t-1}$.

The conditional asset-pricing relation (Equation 11) specifies y_{bt} to be proportional to the conditional covariance of the basis with the excess returns on the world equity portfolio, R^*_{wt}. The time-varying factor of proportionality is the price of covariance risk measured as the conditionally expected excess return on the benchmark portfolio divided by its conditional variance. We allow the price of covariance risk to vary over time. A bivariate model jointly estimates the first and second conditional moments of y_{bt} and R^*_{wt}.

Under rational expectations (informational efficiency), the realized value of the scaled payoff in Equation 11 is equal to the conditional expectation plus an error term ϵ_{bt} that is uncorrelated with past information. The corresponding error term for the benchmark portfolio is ϵ_{wt}. Pairing the time series of the adjusted change in the basis for a particular currency with the excess returns from the benchmark portfolio gives the test equation system

$$y_{bt}=\gamma_{0b}+\mu_b h_{bwt}\frac{\gamma_w' x_{w,t-1}}{h_{wt}}+\psi_b\epsilon_{b,t-1}+\epsilon_{bt}, \qquad (13)$$
$$R^*_{wt}=\gamma_w' x_{w,t-1}+\epsilon_{wt}.$$

In Equation 13, $x_{w,t-1}$ is a vector of instruments (an intercept; the lagged excess return on the benchmark portfolio; $(R_{t-1} - \bar{Z}_{t-1}) / \bar{Z}_{t-1}$, i.e., the relative difference between the U.S. and an average non-U.S. interest rate and the relative difference between the DM and the average non-U.S. interest rate) used to predict the benchmark portfolio return; and μ_b is a parameter that can be restricted to zero to exclude the intertemporal risk premium from the model. Also, h_{bt} is the estimated conditional variance of the adjusted change in the basis, h_{wt} is that for the excess return on the benchmark portfolio, and h_{bwt} is the estimated conditional covariance between the two.

Time variation in the conditional second moments of financial data has been extensively documented (see the survey by Bollerslev, Chou, & Kroner, 1990). We parameterize the conditional covariance matrix associated with Equation 13 using the Engle and Kroner (1995) positive definite form for generalized ARCH. We also allow for asymmetric ARCH (Glosten, Jagannathan, & Runkle, 1993) by adding $u_{bt} = \min\{0,\epsilon_{bt}\}$ and $u_{wt} = \min\{0,\epsilon_{wt}\}$. The vector of error terms, $\epsilon_t' \equiv [\epsilon_{bt}\ \epsilon_{wt}]$, is assumed to have a conditional bivariate normal distribution with a mean zero and conditional covariance matrix,

$$H_t = C'C + A'\epsilon_{t-1}\epsilon'_{t-1}A + D'u_{t-1}u'_{t-1}D + B'H_{t-1}B + G_{t-1} \quad (14)$$

in which A, D and B are symmetric parameter matrices and C is an upper triangular parameter matrix. For example, when D is set to zero for purposes of testing symmetric generalized ARCH, we can express Equation 14 as

$$\begin{bmatrix} h_{bt} & h_{bwt} \\ h_{bwt} & h_{wt} \end{bmatrix} = \begin{bmatrix} c_b & 0 \\ c_{bw} & c_w \end{bmatrix} \begin{bmatrix} c_b & c_{bw} \\ 0 & c_w \end{bmatrix} + \begin{bmatrix} a_b & a_{bw} \\ a_{bw} & a_w \end{bmatrix} \begin{bmatrix} \epsilon^2_{b,t-1} & \epsilon_{b,t-1}\epsilon_{w,t-1} \\ \epsilon_{b,t-1}\epsilon_{w,t-1} & \epsilon^2_{w,t-1} \end{bmatrix} \begin{bmatrix} a_b & a_{bw} \\ a_{bw} & a_w \end{bmatrix} + \begin{bmatrix} b_b & b_{bw} \\ b_{bw} & b_w \end{bmatrix} \begin{bmatrix} h_{b,t-1} & h_{bw,t-1} \\ h_{bw,t-1} & h_{w,t-1} \end{bmatrix} \begin{bmatrix} b_b & b_{bw} \\ b_{bw} & b_w \end{bmatrix} + \begin{bmatrix} \phi'_b g_{b,t-1} & \phi'_{bw} g_{bw,t-1} \\ \phi'_{bw} g_{bw,t-1} & \phi'_w g_{w,t-1} \end{bmatrix}. \quad (15)$$

Note that $g_{b,t-1}$, $g_{w,t-1}$ and $g_{bw,t-1}$ are vectors of instruments known at time t - 1. These vectors are used to add explanatory variables to the variances and the covariance, and also to evaluate the specification of H_t using omitted variable tests. Our maintained model includes an indicator variable in $g_{w,t-1}$ that allows the conditional variance of the benchmark portfolio return to differ for the week of the market crash (the third week of October 1987).

We include a first-order moving-average error term in the test equation for the adjusted basis. Negative autocorrelation may be induced by bid-asked spreads (Roll, 1984). It can also result from taking the first difference of the basis when the futures and spot prices are cointegrated (Beaulieu & Morgan, 1998).

Note that serial correlation could also arise from asynchronous recording of the time series concerned. The futures price is recorded later in the day than the spot price, so that news occurring between these times will affect the futures price but cannot affect the spot price. An important piece of positive news for the currency will then cause the futures price to rise, leading to a strongly positive value of the recorded adjusted basis, followed the next day by a negative value when the spot price adjusts for the information. This results in negative autocorrelation with a first-order moving average form.

Asynchronous recording of data as a source of a moving-average component can be illustrated in the following way. Representing the risk premium in Equations 10 or 11 by π_{t-1} and, for expository reasons, ignoring the scaling by S_{t-1}, the forecast error is:

$$e_t = F_t - S_t - \left[F_{t-1} - S_{t-1}\frac{R_{t-1}}{Z_{t-1}}\right] - \pi_{t-1}. \quad (16)$$

However, the futures price F_t is sampled at t later in the day than the spot price S_{t*} which is sampled at $t*$. Therefore, the error measured from the data available to the researcher is:

$$e_{t*} = F_t - S_{t*} - \left[F_{t-1} - S_{t*-1}\frac{R_{t-1}}{Z_{t-1}}\right] - \pi_{t-1} \quad (17)$$

or, equivalently,

$$e_{t*} = e_t + (S_t - S_{t*}) - (S_{t-1} - S_{t*-1})\frac{R_{t-1}}{Z_{t-1}}, \quad (18)$$

consisting of a random error term plus an MA(1) error component. The error measured from the data available to the researcher is a composite of all three terms and it has a first-order moving-average component induced by the nonsimultaneous recording of the futures and spot prices.

Test Equation System for the Components of the Basis

This section describes the trivariate test equation system that we estimate for each currency. By separating the components of the hedged position but estimating them simultaneously in one system, we can formally test various restrictions concerning the conditional CAPM and intertemporal risk implicit in the bivariate test-equation system. For example, the trivariate system allows us to evaluate whether $\mu_f = \mu_s$. The trivariate system consists of equations for the futures, the spot, and the benchmark portfolio.

Let the rate of change of the futures price be $y_{ft} = (F_t / F_{t-1} - 1)$ and let the scaled excess return on an uncovered position in a Eurocurrency deposit be $y_{st} = (S_t / S_{t-1}) - (R_{t-1} / Z_{t-1})$. The trivariate test-equation system is:

$$\begin{aligned} y_{ft} &= \gamma_{0f} + \mu_f h_{fwt}\frac{\gamma_w' x_{w,t-1}}{h_{wt}} + \psi_f\epsilon_{f,t-1} + \epsilon_{ft}, \\ y_{st} &= \gamma_{0s} + \mu_s h_{swt}\frac{\gamma_w' x_{w,t-1}}{h_{wt}} + \psi_s\epsilon_{s,t-1} + \epsilon_{st}, \\ R^*_{wt} &= \gamma_w' x_{w,t-1} + \epsilon_{wt} \\ H_t &= C'C + A'\epsilon_{t-1}\epsilon_{t-1}'A + D'u_{t-1}u'_{t-1}D + B'H_{t-1}B + G_{t-1}. \end{aligned} \quad (19)$$

In this case the matrices associated with the conditional covariance matrix H_t are three-dimensional instead of two-dimensional as in Equations 14 and 15.

Data

Futures prices for the British pound, Canadian dollar, Deutsch mark, Japanese yen, and Swiss franc (BP, CD, DM, JY, SF, respectively), were taken from a file provided by the University of Chicago's Center for Research in Futures Markets and updated with data from Reuters. We used futures settlement prices (recorded, depending on the currency, at 1:16 p.m. to 1:26 p.m. CST) for the contracts with the shortest maturity available at any time up to and including the last Wednesday before the end of the life of the contract. In order to avoid day-of-the-week effects, we used weekly data, which implies that we were ignoring intraweek marking to market. We computed the Wednesday-to-Wednesday rate of change of the futures price. If Wednesday was a holiday, Thursday prices were substituted. Our series of 626 observations starts on January 2, 1980, with an effective sample size of 625, because the first observation was used in the start of the estimation.

In the sample period, the institutionally imposed rules specifying the maximum price change that can occur in one day were relatively unimportant; the limits were not tight for these five currencies, and they were removed entirely on February 22, 1985. For the closest to maturity contract used in this paper, there were no occurrences of limit moves in the BP, four in the CD, eight in the DM, five in the JY, and three in the SF. Of these limit moves, only six occurred on a Wednesday, and we made no adjustment for them. Kodres (1988) and Morgan and Trevor (in press) gave a more complete discussion of price limits in empirical work.

Foreign currency spot prices are the average of bid and asked prices from the NY interbank market recorded at 2:00 p.m. EST. Our sample has not been updated beyond the 626 weeks due to difficulty in matching these data, originally chosen so that they are sampled relatively close to the time of day that futures settlement prices are recorded. Seven-day Eurocurrency interest rates were used to compute excess returns and as instruments to predict returns on the benchmark portfolio. When the domestic or any foreign interest rate was unavailable because of holidays, we substituted all rates for the previous day.

Results

QML estimation is implemented with standard errors computed to allow robust inference in the presence of potential departures from conditional normality (Bollerslev & Wooldridge, 1992). Tables 1 to 6 and Figures 1 and 2 summarize the main results for the various positions in each currency. In particular, Table 1 reports the conditional mean parameter and robust standard error estimates for the basis model (Equations 13 and 14) applied to each currency. Table 2 summarizes some diagnostic tests on the standardized residuals, Table 3 reports Kroner-Ng indicator tests for misspecification, and Table 4 provides some robust conditional-moment test statistics associated with variables excluded from the basis model. Table 4 also reports a likelihood ratio test (LRT) for excluding a systematic intertemporal risk premium. Table 5 summarizes the results of a specification test for the conditional CAPM representation of the IAPM for the time series evolution of the basis.

Finally, Table 6 evaluates some restrictions implicit in the bivariate basis model using results from an unrestricted trivariate specification of the separate components of the basis. Figures 1 and 2 illustrate the estimated ex ante weekly risk premiums associated with the futures and spot positions for the JY, providing graphical support for the test results concerning intertemporal risk summarized in Tables 4 and Table 6.

Results for the Basis Model

Table 1 summarizes results relevant to the time series evolution of the basis obtained from estimation of the basis model (Equations 13 and 14) for each currency. The conditional capital-asset-pricing implementation of the basis model (Equation 11) stipulates that $\mu_b = 1$, $\gamma_{0b} = 0$ and $\psi_b = 0$ in Equation 13. Imposing the restriction $\mu_b = 1$, which is implied by the conditional CAPM specification, Table 1 reports coefficient and robust standard error estimates for the conditional means of the hedged postion and the benchmark portfolio. Note that the intercept is significantly different from zero for the DM and the JY and the MA(1) term is significantly negative in all currencies. The latter result is consistent with the various explanations discussed in the first part of the "Test Equations" section, including asynchronous recording of the futures and spot prices used to compute y_{bt}, bid-asked spreads, and co-integrated futures and spot prices.

Table 2 reports some residual-based diagnostic tests on the standardized residuals associated with the y_{bt} component of the basis model. These tests do not reveal any inadequacy of the estimated models. Table 3 summarizes results from sign and size misspecification indicator tests (Kroner & Ng, 1998) for our parameterization of the conditional variances and covariances. Again, none of these tests indicate misspecification.

The first panel of Table 4 reports robust conditional moment test statistics (Wooldridge, 1990) associated with variables that were excluded from the conditional mean of the adjusted change in the basis, y_{bt}, in the model reported in Table 1. Remaining time-to-expiration, $T - t$, for the relevant futures contract does not add any explanatory power, nor does the relative difference between the particular and average non-U.S. interest rates $(Z_{t-1} / \bar{Z}_{t-1}) - 1$.

Table 1
Intertemporal Model of the Basis: Estimates

$$y_{bt} = \gamma_{0b} + \mu \frac{h_{bwt}}{h_{wt}} \gamma'_w x_{w,t-1} + \psi_b \epsilon_{b,t-1} + \epsilon_{bt},$$

$$R^*_{wt} = \gamma'_w x_{w,t-1} + \epsilon_{wt}.$$

	Estimates with $\mu = 1$				
	BP	CD	DM	JY	SF
γ_{0b}	-0.0060	0.0035	-0.0080	-0.0102	-0.0010
	(0.0032)	(0.0018)	(0.0034)	(0.0028)	(0.0037)
ψ_b	-0.584	-0.491	-0.621	-0.630	-0.534
	(0.045)	(0.040)	(0.052)	(0.056)	(0.034)
γ_{0w}	-0.272	-0.260	-0.247	-0.261	-0.305
	(0.153)	(0.158)	(0.143)	(0.153)	(0.148)
γ_{1w}	0.084	0.101	0.101	0.076	0.084
	(0.047)	(0.043)	(0.048)	(0.048)	(0.041)
γ_{2w}	-0.363	-0.376	-0.374	-0.390	-0.384
	(0.160)	(0.133)	(0.199)	(0.162)	(0.142)
γ_{3w}	-1.124	-1.069	-1.042	-1.080	-1.189
	(0.342)	(0.357)	(0.336)	(0.366)	(0.337)

Note. Robust standard errors are in parentheses. Coefficients in the parameter vector γ_w refer to instruments used to predict the benchmark portfolio excess return, that is, an intercept, the lagged excess return on the benchmark portfolio, the relative difference between the U.S. and an average non-U.S. interest rate, and the relative difference between the DM and the average non-U.S. interest rate, respectively.

The second panel of Table 4 reports likelihood ratio test (LRT) statistics associated with an explicit restriction imposed on the basis model reported in Table 1. In particular, in order to evaluate the zero intertemporal risk hypothesis, we compare models with μ unrestricted to those with μ restricted to be zero so that the risk term is excluded from the conditional mean of the adjusted change in the basis, y_{bt}. This restriction of zero intertemporal risk is not rejected for any of the currencies although it is marginal for the JY.

A Specification Test for the Conditional CAPM Representation

Recall that R^*_{wt} is the excess return from the benchmark portfolio, y_{bt} is the adjusted change in the basis as in Equation 12, R_{t-1} is the gross (nominally riskless) domestic interest rate from t - 1 to t, and M_t is the nominal benchmark variable or the intertemporal rate of substitution of domestic currency from t - 1 to t.

Table 2
Basis Model: Residual-Based Diagnostic Tests

	BP	CD	DM	JY	SF
R_b	-1.64	0.12	-0.20	-1.92	-1.96
	[0.10]	[0.90]	[0.84]	[0.36]	[0.05]
$Q_b(16)$	7.42	7.37	9.66	15.78	6.80
	[0.96]	[0.97]	[0.88]	[0.47]	[0.98]
$Q^2_b(16)$	10.16	9.23	4.19	4.73	4.28
	[0.86]	[0.90]	[0.99]	[0.99]	[0.99]

Note. R_b is the test statistic for runs above the median and the p values in square brackets are for the unit normal distribution. $Q_b(16)$, $Q^2_b(16)$ are the Ljung-Box (1978) test statistics for the first 16 lags of the autocorrelation function for the standardized residuals for the basis and their squares, respectively; the p values are for the χ^2_{16} distribution.

Our asset-pricing model implies that:

$$E_{t-1}R^*_{wt} = -R_{t-1}cov_{t-1}(R_{wt}, M_t). \quad (20)$$
$$E_{t-1}y_{bt} = -R_{t-1}cov_{t-1}(y_{bt}, M_t).$$

It thus follows that:

$$E_{t-1}y_{bt} = \frac{cov_{t-1}(y_{bt}, M_t)}{cov_{t-1}(R_{wt}, M_t)} E_{t-1}R^*_{wt}. \quad (21)$$

Treating M_t as a latent variable (see, for example, Mark, 1988), consider a projection in which the error term is uncorrelated with the instruments,

$$M_t = c_0 + c_1 R^*_{wt} + c_2 y_{bt} + e_t. \quad (22)$$

Using Equation 22,

$$cov_{t-1}(y_{bt}, M_t) = c_1 cov_{t-1}(y_{bt}, R_{wt}) + c_2 var_{t-1}(y_{bt}),$$
$$cov_{t-1}(R_{wt}, M_t) = c_1 var_{t-1}(R_{wt}) + c_2 cov_{t-1}(y_{bt}, R_{wt}), \quad (23)$$

so that, defining $\delta = c_2/c_1$, Equation 21 can be rewritten as

$$E_{t-1}y_{bt} = \frac{cov_{t-1}(y_{bt}, R_{wt}) + \delta var_{t-1}(y_{bt})}{var_{t-1}(R_{wt}) + \delta cov_{t-1}(y_{bt}, R_{wt})} E_{t-1}R^*_{wt}. \quad (24)$$

Note that the conditional CAPM is nested in Equation 24 and can be tested in our bivariate system as H_0: $\delta = 0$ against H_1: $\delta \neq 0$. The rejection of our joint hypothesis may be interpreted in more than one way; it may indicate an inefficient benchmark portfolio (as in

Table 3
Basis Model: Kroner-Ng Misspecification Indicator Tests

Test object	Misspecification indicator	BP	CD	DM	JY	SF
$\epsilon_{1t}\epsilon_{2t}-h_{12t}$						
	$I(\epsilon_{1t-1}<0;\ \epsilon_{2t-1}<0)$	0.01 [0.94]	1.96 [0.16]	1.37 [0.24]	0.05 [0.83]	0.08 [0.78]
	$I(\epsilon_{1t-1}<0;\ \epsilon_{2t-1}>0)$	1.52 [0.22]	3.91 [0.05]	0.51 [0.48]	0.10 [0.76]	0.02 [0.89]
	$I(\epsilon_{1t-1}>0;\ \epsilon_{2t-1}<0)$	1.29 [0.26]	0.00 [0.98]	0.29 [0.59]	1.12 [0.29]	0.67 [0.41]
	$I(\epsilon_{1t-1}>0;\ \epsilon_{2t-1}>0)$	3.86 [0.05]	0.10 [0.76]	0.13 [0.72]	0.15 [0.70]	1.83 [0.88]
	$I(\epsilon_{1t-1}<0)$	1.19 [0.28]	0.16 [0.69]	0.03 [0.87]	0.23 [0.63]	0.14 [0.71]
	$\epsilon_{1t}^2 I(\epsilon_{2t-1}<0)$	1.04 [0.31]	1.97 [0.16]	0.26 [0.61]	0.50 [0.48]	1.10 [0.29]
$\epsilon_{1t}^2-h_{11t}$						
	$I(\epsilon_{1t-1}<0)$	0.02 [0.89]	0.01 [0.93]	0.41 [0.52]	2.12 [0.15]	0.00 [0.99]
	$\epsilon_{1t}^2 I(\epsilon_{1t-1}<0)$	0.26 [0.61]	0.21 [0.65]	0.01 [0.94]	0.88 [0.35]	0.01 [0.92]
$\epsilon_{2t}^2-h_{22t}$						
	$I(\epsilon_{2t-1}<0)$	0.84 [0.36]	1.35 [0.25]	1.32 [0.25]	1.02 [0.31]	1.29 [0.26]
	$\epsilon_{2t}^2 I(\epsilon_{1t-1}<0)$	1.03 [0.31]	1.21 [0.27]	1.29 [0.26]	1.11 [0.29]	1.18 [0.28]

Note. $I(\ )$ is an indicator variable taking the value of one if the condition is true and zero otherwise. p values in the square brackets are for the χ_1^2 distribution.

Roll, 1977) or a failure of the conditional CAPM. Table 5 reports LRT statistics for H_0 against H_1. Overall, the model is not rejected using this specification test.

Some Results for the Separate Components of the Basis Position

It is useful to analyze the futures and spot components of the hedged position separately. Table 6 presents test statistics associated with some of the cross-equation restrictions implicit in Equations 13 and 14 but explicit in the trivariate system (Equation 19). Estimating the components of the hedge position separately but simultaneously allows one to evaluate whether the conditional CAPM applies equally well to both the futures and spot components. Panel A of Table 6 indicates that we do not reject the restriction that $\mu_f = \mu_s$, except perhaps for the SF. In Panel B, the rejection of the hypothesis that

Table 4
Basis Model: Tests of Restrictions

	BP	CD	DM	JY	SF
Panel A: Robust CM tests for excluded variables					
$T-t$	0.20	1.01	0.00	0.41	0.11
	[0.65]	[0.31]	[0.97]	[0.52]	[0.74]
$(Z_{t-1}/\bar{Z}_{t-1}) - 1$	1.67	0.18	3.53	4.66	1.31
	[0.20]	[0.68]	[0.06]	[0.03]	[0.25]
Panel B: *LRT* for zero intertemporal risk associated with the futures basis					
$\mu = 0$	1.90	0.01	0.11	3.50	0.36
	[0.17]	[0.91]	[0.74]	[0.06]	[0.55]

Note. T-t is the remaining life of the futures contract, $(Z_{t-1}/\bar{Z}_{t-1}) - 1$ is the relative difference between the particular and average non-U.S. interest rates. LRT is the likelihood ratio test. p values in square brackets are for the χ^2_1 distribution.

Table 5
A Specification Test for the Conditional CAPM Representation of the Basis Model

Tests of $\delta = 0$ against $\delta \neq 0$:	BP	CD	DM	JY	SF
LRT	1.16	0.03	1.87	9.37	2.05
p value	[0.28]	[0.86]	[0.17]	[0.01]	[0.15]
Robust t statistic	-0.92	0.16	-0.79	-1.44	-1.77
p value	[0.36]	[0.87]	[0.43]	[0.15]	[0.08]

Note. LRT is the likelihood ratio test statistic for which the p values in square brackets are for the χ^2_1 distribution. For the robust t statistics, the p values in square brackets are for the unit normal distribution.

$\mu_f = \mu_s = 0$ in favour of $\mu_f = \mu_s \neq 0$, for all currencies, indicates that covariance risk is important for both the futures and spot components of the trivariate model.

Estimating the separate components of the basis also allows us to compare the time series properties of the estimated risk premiums. For example, the results in McCurdy and Morgan (1991, 1992a) indicated that uncovered foreign currency spot (Eurocurrency deposit) positions have statistically significant time-varying covariance risk associated with them, as do uncovered positions in foreign currency futures. Opposite positions in the spot and futures market, as in Equation 8, may lead to an effective hedge and insignificant intertemporal risk associated with the foreign currency futures basis.

Figures 1 and 2 illustrate the above result in this sample for the JY. That is, Figures 1 and 2 illustrate the estimated risk premiums associated with the futures and spot positions respectively. The time-series behaviour of the plots are very similar, indicating that both the quantity of covariance risk and the required return per unit of risk are roughly equal for the two positions in a given currency.

Table 6
Trivariate Model of Futures and Spots and Benchmark Portfolio

$$y_{ft} = \gamma_{0f} + \mu_f \frac{h_{fwt}}{h_{wt}} \gamma_w x_{w,t-1} + \psi_f \epsilon_{f,t-1} + \epsilon_{ft},$$

$$y_{st} = \gamma_{0s} + \mu_s \frac{h_{swt}}{h_{wt}} \gamma_w x_{w,t-1} + \psi_s \epsilon_{s,t-1} + \epsilon_{st},$$

$$R^*_{wt} = \gamma_w x_{w,t-1} + \epsilon_{wt}.$$

	BP	CD	DM	JY	SF
Panel A: Tests of $\mu_f = \mu_s$ against $\mu_f \neq \mu_s$					
LRT	0.48	3.64	1.30	0.01	4.45
	[0.49]	[0.06]	[0.25]	[0.91]	[0.03]
Panel B: Tests of $\mu_f = \mu_s = 0$ against $\mu_f = \mu_s$					
LRT	34.83	23.94	7.64	33.44	26.74
	[0.00]	[0.00]	[0.01]	[0.00]	[0.00]

Note. LRT is the likelihood ratio test statistic for which the p values in square brackets are for the χ^2_1 distribution.

Conclusion

We derive a testable equilibrium model for the intertemporal evolution of the basis in foreign currency futures markets. Our measure of risk constrasts with that prevalent in earlier analyses. That is, our model prices nondiversifiable or systematic intertemporal risk. Empirical implementation utilizes a conditional CAPM in which both the quantity and price of covariance risk are free to vary and for which the benchmark portfolio represents extensive international diversification.

For this application to offsetting positions in foreign currency spot (Eurocurrency deposit) and futures contracts, estimated intertemporal risk is insignificantly different from zero, the risk in the futures position offset-

Figure 1.
JY Futures.

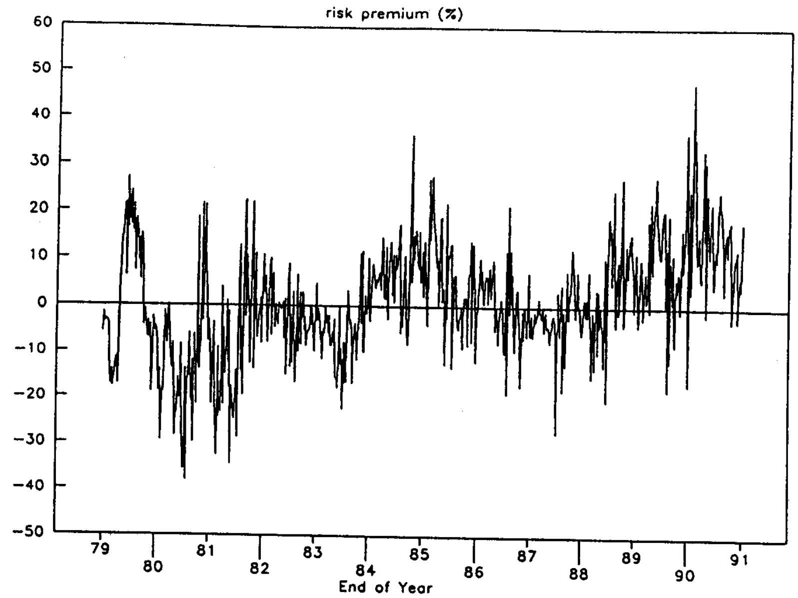
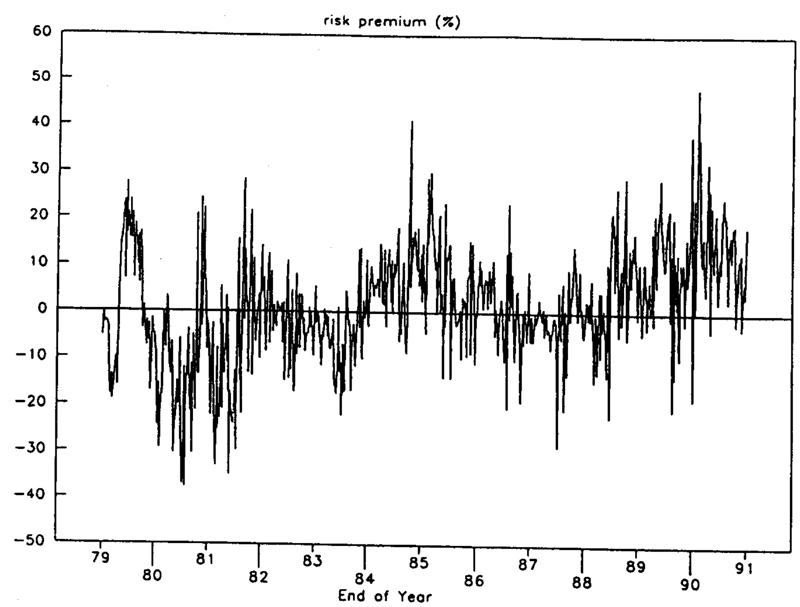


Figure 2.
JY Spot.



ting that in the spot. That is, an effective hedge is assured in these circumstances.

The futures data used were for the contract with the shortest remaining life at any given time. These data are likely to reflect the smallest differences between futures and forward prices because of minimal interest rate risk Therefore, our results suggest that for risk management with short horizons there will be no serious error in approximating the futures price by the forward price. What is not clear is whether this approximation is justifiable for longer horizons than the maximum time to delivery date of the futures contracts in our data. The longer maturity futures contracts are probably not sufficiently actively traded to allow meaningful tests to determine whether significant intertemporal risk associated with the futures basis results when the interest rate risk can be expected to be much greater.

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Notes

1. Some hedge funds pursue strategies that focus on relative rather than absolute prices. Such strategies have been called "expectations arbitrage" ("Risk Business," 1998, p. 22), which suggests that the distinction between speculation and arbitrage is not always clear-cut.
2. Assuming complete markets, continuous trading, and a correct model, it may be possible to maintain a perfect hedge. However, in the presence of discrete marking to market and market imperfections such as transactions costs, a perfect hedge may be unfeasible or overly expensive.
3. See, for example, Khoury and Yourougou (1991).
4. See, for example, Chan, Chan, and Karolyi (1991) and Miller, Muthuswamy, and Whaley (1994).