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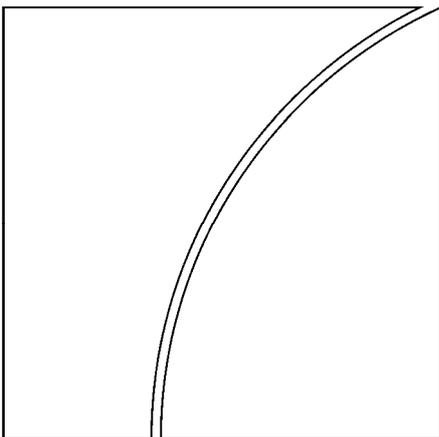
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Price discovery from cross-currency and FX swaps: a structural analysis

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Abstract

This paper investigates the relative role of price discovery between two long-term swap contracts that exchange U.S. dollars for Japanese yen – the cross-currency basis swap and the foreign exchange (FX) swap – using structural state space models. Our main findings are that: (i) the currency swap market plays a much more dominant role in price discovery than the FX swap market; and (ii) FX swap prices tend to under react to changes in the efficient price, while cross-currency swap prices react almost entirely to them.

1. Introduction

This paper investigates the relative role of price discovery between two long-term swap contracts that exchange U.S. dollars for Japanese yen: the cross-currency swap contract and the foreign exchange (FX) swap contract. These contracts have been important for both Japanese and non-Japanese banks seeking to raise foreign currencies. Although both contracts exchange dollars for yen, they differ in their cash flow characteristics: cross-currency swaps exchange floating rates during the term of the contract, while FX swaps implicitly exchange fixed rates. Historically, liquidity in the long-term FX swap market has been low compared with the cross-currency swap market, and hence most studies have focused on cross-currency swap prices, for example when testing long-term covered interest parity. In recent years, however, the liquidity of the long-term FX swap market has improved substantially, and arbitrage activity between the two markets has increased. Hence, in this paper, we attempt to assess the relative role of price discovery in each swap market. To that end, we directly formulate and estimate both the component of prices due to microstructural frictions and the permanent component, as suggested by the price discovery literature.

In the next section, we argue that the pricing of cross-currency and FX swap markets should allow for differential risk premiums. In tests of long-term interest rate parity, the literature has

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traditionally abstracted from differential risk premiums between counterparties, as well as between currencies.² While this simplification seems to have been reasonable prior to the late 1990s, the deterioration in the creditworthiness of Japanese banks, due mainly to the non-performing loan problem, introduced a so-called Japan premium not only in short-term money markets, but also in the longer-term interbank markets.³ We show that in order to explain the actual price movements of cross-currency and FX swaps, it is essential to allow for differential risk premiums between Japanese and non-Japanese banks, as well as between U.S. dollar and yen markets.⁴

Broadly speaking, there are two main approaches to testing price discovery in markets. First, Gonzalo and Granger [1995] and Hasbrouck [1995] propose a price discovery measure based on the vector error correction model (VECM), respectively. We call this type of methodology a reduced-form approach. Second, Menkveld, Koopman, and Lucas [2007] model the unobserved efficient price common to cross-listed stocks using a state space model, and successfully gauge the relative role of price discovery between the two markets under study. Here, the efficient price refers to a permanent component of prices that prevail in the absence of microstructural noises (Lehmann [2002]). In most applications of this kind, the efficient price is assumed to follow a random walk, because, in efficient markets, realised changes in prices are unforecastable given information at current time (Samuelson [1965]). Following Harvey [1989], we call this type of methodology a structural-form approach.⁵

For several reasons, we have chosen the structural-form approach as the principal methodology in this paper. Although the reduced-form approach places fewer *ad hoc* restrictions on data, the interpretability of estimation results is more straightforward in the structural-form approach. In addition, the structural-form approach facilitates testing of partial vs. complete adjustment of market prices to the efficient price, as well as under- or overreaction of market prices to the efficient price. We do use the more conventional reduced-form approach to check the robustness of our estimation results.

The rest of the paper is organised as follows. Section 2 briefly describes cross-currency swap and FX swap markets and discusses their recent development. Section 3 describes the no-arbitrage condition between prices in the two swap markets taking into account differential risk premiums. Section 4 describes the data. Section 5 reviews the structural models we use. Section 6 reports the estimation results. Section 7 concludes.

² See Popper [1993], Fletcher and Taylor [1994], and Takezawa [1995], among others. They use the currency swap data from the late 1980s or early 1990s to test long-term interest parity, and find non-negligible deviations from the parity, although such deviations diminished over time.

³ For more details of the Japan premium, see Covrig, Low, and Melvin [2004], and Ito and Harada [2000], among others. Baba et al. [2006] show that the quantitative easing policy conducted by the Bank of Japan contained credit risks for Japanese banks in the short-term money markets, but a non-negligible credit risk premium remained in the long-term credit markets, including the straight bond and credit derivatives markets until 2003.

⁴ This setting likely has some relevancy for other currency pairs including the U.S. dollar and euro, particularly when we examine cross-currency and FX swap markets during the financial market crisis that erupted in the summer of 2007. In that period, both swap prices were substantially distorted in a direction indicating higher riskiness for European banks than for U.S. banks in U.S. dollar funds. See Baba, Packer, and Nagano [2008] for more details.

⁵ Harvey [1989] defines a structural time-series model as one that is set up in terms of unobservable components that have a direct interpretation.

2. Basic schemes of the cross-currency basis swap and FX swap

2.1 Cross-currency basis swap

There are numerous types of cross-currency swap contracts, among which the most widely used in recent years is a type of contract named the cross-currency basis swap.⁶ A typical cross-currency basis swap (hereafter “currency swap”) agreement is a contract in which Japanese banks borrow U.S. dollars (USD) from, and lend yen (JPY) to, non-Japanese banks simultaneously. Figure 1(i) illustrates the flow of funds associated with this currency swap. At the start of the contract, bank A (a Japanese bank) borrows X USD from, and lends $X \times S$ JPY to, bank B (a non-Japanese bank), where S is the FX spot rate at the time of contract. During the contract term, bank A receives JPY $3M \text{ LIBOR} + \alpha$ from, and pays USD $3M \text{ LIBOR}$ to, bank B every three months.⁷ When the contract expires, bank A returns X USD to bank B, and bank B returns $X \times S$ JPY to bank A.⁸ At the start of the contract, both banks decide α , which is the price of the basis swap. In other words, bank A (B) borrows foreign currency by putting up its home currency as collateral, and hence this swap is effectively a collateralised contract.

These currency swaps have been employed by both Japanese and non-Japanese banks to fund foreign currencies, for both their own and their customers’ account, including multinational corporations engaged in foreign direct investment. Currency swaps have been also used as a hedging tool, particularly for issuers of so-called *Samurai* bonds, which are JPY-denominated bonds issued in Japan by non-Japanese companies. By nature, most of these transactions are long-term, ranging from one year to 30 years.

2.2 FX swap

A typical FX swap agreement is also a contract in which Japanese banks borrow USD from, and lend JPY to, non-Japanese banks simultaneously.⁹ The main differences from the currency swap are that: (i) during the contract term, there are no exchanges of floating interest between JPY and USD rates; and (ii) at the end of the contract, the different amount of funds is returned compared with the amount exchanged at the start.

Figure 1(ii) illustrates the flow of funds associated with the FX swap. At the start of the contract, bank A (Japanese bank) borrows X USD from, and lends $X \times S$ JPY, to bank B (non-Japanese bank), where S is the FX spot rate at the time of contract. When the contract expires, bank A returns X USD to bank B, and bank B returns $X \times F$ JPY to bank A, where F is the FX forward rate as of the start of contract. As is the case with currency swaps, FX swaps are effectively collateralised contracts.

FX swaps have been employed by both Japanese and non-Japanese banks for funding foreign currencies, for both their own and their customers’ account, including exporters, importers, and Japanese institutional investors in hedged foreign bonds. FX swaps have also been used for speculative trading. The most liquid term is shorter than one year, but in recent

⁶ The most traditional cross-currency swaps are the contracts in which fixed interest rates are exchanged between the two currencies. Another example is the coupon swaps in which interest rates are exchanged between the currencies, but there is no exchange of principals at the start and end of the contract.

⁷ 3M LIBOR is the three-month London Interbank Offered Rate. The difference in α between Japanese and non-Japanese banks is generally much smaller than the difference in uncollateralised interest rates between those banks since cross-currency swap contracts are effectively collateralised.

⁸ S here is also the FX spot rate as of the time of contract.

⁹ The explanation here follows Nishioka and Baba [2004].

years, transactions with longer maturities have been actively conducted for purposes such as foreign currency funding for corporate direct investments and arbitrage activities with cross-currency swaps. In fact, many market participants point out that the liquidity of FX swaps with maturities longer than one year has improved during the past several years.

3. No-arbitrage condition between currency swap and FX swap markets

3.1 Basis setup

In this section, we construct the no-arbitrage condition between currency swap and FX swap markets. Most of the literature uses only currency swap prices to test the long-term covered interest parity, ignoring the differential risk premiums between lenders and borrowers, as well as between currencies, although some note its potential importance.¹⁰

Figure 2 shows risk premiums for Japanese and non-Japanese banks in the USD and JPY markets, estimated by taking advantage of the difference in panel banks for LIBOR (London Interbank Offered Rate) and TIBOR (Tokyo Interbank Offered Rate).¹¹ Only a few Japanese banks are included in the LIBOR panel, while most of the TIBOR panel are Japanese banks. Thus, relatively speaking, TIBOR is expected to reflect the risk premium for Japanese banks, and LIBOR the risk premium for non-Japanese banks. Here, we note substantial differences in the risk premiums between Japanese and non-Japanese banks in the same currency market, as well as between the USD and JPY markets for the same bank group. The differential risk premiums between Japanese and non-Japanese banks have usually been explained by the so-called Japan premium story.¹² Since the late 1990s, deterioration in the creditworthiness of Japanese banks relative to other advanced nations' banks has significantly influenced Japanese banks' foreign currency funding, particularly USD funding. The deterioration in creditworthiness was originally caused by the non-performing loan problem triggered by the bursting of the asset bubbles in the early 1990s.

More interestingly, we can observe the larger and more persistent differential risk premiums between the USD and JPY markets for the same bank group.¹³ Figure 2 shows that risk premiums are much higher in the USD market than in the JPY market for both Japanese and non-Japanese banks and fluctuate widely over time. Market participants often cite a difference in main participants, and hence in attitudes toward risk evaluation as the main

¹⁰ For the long-term interest rate parity, see Popper [1993], Fletcher and Taylor [1994, 1996], Fletcher and Sultan [1997], and Takezawa [1995], among others. Regarding differential risk premiums, Popper [1993] mentions the potential bias from not considering them, particularly in Euro-currency markets.

¹¹ Risk premiums for Japanese banks in the USD (JPY) markets are calculated as one-year USD-TIBOR (JPY-TIBOR) minus yields on one-year U.S. (Japanese) government bonds. Risk premiums for non-Japanese banks in the USD (JPY) markets are calculated as one-year USD-LIBOR (JPY-LIBOR) minus yields on one-year U.S. (Japanese) government bonds. Since the end of March 2007, USD-TIBOR (JPY-TIBOR) has been calculated based on rates quoted by a panel of nine (15) banks, of which seven (14) are Japanese banks. On the other hand, USD-LIBOR (JPY-LIBOR) has been based on rates quoted by a panel of 16 (16) banks, of which two (four) are Japanese banks.

¹² For the Japan premium, see Covrig, Low, and Melvin [2004], Ito and Harada [2000], and Peek and Rosengren [2001], for instance.

¹³ Excessively low U.S. Treasury bill yields due chiefly to scarcity premiums could also be a factor. But the same might be true for Japanese Treasury bill yields.

reason for this.¹⁴ Hence, in this paper, we explicitly allow for such differential risk premiums in order to construct the no-arbitrage conditions linking the currency swap and FX swap market.

Specifically, we start by describing the typical funding structure of Japanese and non-Japanese banks, following Nishioka and Baba [2004]. The funding costs in the JPY and USD markets are the sum of the reference interest rate, an interest rate swap (IRS) rate, in our case, that does not reflect differential risk premiums and the risk premium for the representative Japanese or non-Japanese bank in each market.¹⁵ Let r_{JPY} (r_{USD}) denote the JPY (USD) reference interest rate, ϕ_{JPY} (ϕ_{USD}) the risk premium for the Japanese bank in the JPY (USD) market, and θ_{JPY} (θ_{USD}) the risk premium for the non-Japanese bank in the JPY (USD) market. The main source of risk premiums is the credit or default risk of borrowers, but here we expand the notion of risk premiums to involve price movements caused by *ex ante* supply-demand and liquidity conditions.

As shown in Figure 3, the Japanese (non-Japanese) bank has two alternative USD (JPY) funding sources: (i) raising USD (JPY) directly from the USD (JPY) cash market; and (ii) first raising JPY (USD) from the JPY (USD) cash market and then exchanging it for USD (JPY) in the currency swap or FX swap market.

3.2 Currency swap market

Given the basic funding structure above, let us first look at the no-arbitrage condition for the currency swap market. Because the interest rates in the currency swap are floating rates, for comparison with the FX swap prices we need to exchange floating rates with fixed rates through IRS. After this conversion and ignoring the transaction costs, the no-arbitrage conditions for the currency swap market can be written as¹⁶

$$1 + r_{USD} + \phi_{USD} = (1 + r_{JPY} + \phi_{JPY}) + [(1 + r_{USD}) - (1 + r_{JPY} + \alpha)] \quad (1)$$

for Japanese banks

$$1 + r_{JPY} + \theta_{JPY} = (1 + r_{USD} + \theta_{USD}) + [(1 + r_{JPY} + \alpha) - (1 + r_{USD})]. \quad (2)$$

for non-Japanese banks

Equilibrium in the currency swap market requires

$$\phi_{JPY} - \phi_{USD} = \theta_{JPY} - \theta_{USD} = \alpha. \quad (3)$$

The left-hand side of equation (3) denotes the difference in the risk premiums for the Japanese banks between the JPY and USD markets, and the right-hand side the difference in the risk premiums for the non-Japanese banks between the JPY and USD markets. Note here that without considering the differential risk premiums, the price for the currency swap α should be zero and hence the observed negative α cannot be rationalised. The generalisation of the no-arbitrage relationship we have proposed above, however, shows that α can take on both positive and negative values without violating the no-arbitrage condition.

¹⁴ Until quite recently, there were non-negligible differences in Japanese and U.S. credit ratings for the same Japanese firms, the ratings set by U.S. agencies being generally lower than those of Japanese agencies for the same entities.

¹⁵ In this paper, we use the IRS rates, as such reference rates are broadly the same between Japanese and non-Japanese banks, due to the need to convert floating rates in the cross-currency swaps into the fixed rate using IRS for comparison of prices between the cross-currency swap and FX swap.

¹⁶ The transaction costs are ignored merely for simplicity. We consider the potential transaction costs in the empirical analysis.

¹⁷ Note that these conditions hold even in the case that Japanese (non-Japanese) banks raise the JPY (USD).

3.3 FX Swap Market

Second, let us look at the no-arbitrage conditions for the FX swap market, which can be written as

$$1 + r_{USD} + \phi_{USD} = \frac{S}{F}(1 + r_{JPY} + \phi_{JPY}) \quad \text{for Japanese banks} \quad (4)$$

$$1 + r_{JPY} + \theta_{JPY} = \frac{F}{S}(1 + r_{USD} + \theta_{USD}). \quad \text{for non-Japanese banks} \quad (5)$$

Equilibrium in the FX swap market requires

$$\frac{1 + r_{JPY} + \theta_{JPY}}{1 + r_{JPY} + \phi_{JPY}} = \frac{1 + r_{USD} + \theta_{USD}}{1 + r_{USD} + \phi_{USD}}. \quad (6)$$

Equation (6) can be approximated as

$$\phi_{JPY} - \phi_{USD} \approx \theta_{JPY} - \theta_{USD}. \quad (7)$$

To facilitate the interpretation of equation (7), let us implicitly define β as

$$\frac{F}{S} = \frac{1 + r_{JPY} + \beta}{1 + r_{USD}}. \quad (8)$$

From equations (4), (5), and (8), we obtain

$$\phi_{JPY} - \phi_{USD} \approx \theta_{JPY} - \theta_{USD} \approx \beta. \quad (9)$$

Equation (9) means that the implicitly defined FX swap price β is approximately equivalent to the difference in the risk premiums for each bank between the JPY and USD markets. Again, without allowing for differential risk premiums, β should be zero.

3.4 No-Arbitrage Condition between the Currency Swap and FX Swap Markets

We can now combine equations (3) and (9) to derive the no-arbitrage condition between the currency swap and FX swap markets as follows:

$$\alpha \approx \beta \approx \phi_{JPY} - \phi_{USD} = \theta_{JPY} - \theta_{USD}. \quad (10)$$

α and β reflect the same fundamentals, and hence should be in the no-arbitrage relationship.

4. Data

For α , we use the cross-currency basis swap price compiled and reported by Bloomberg. On the other hand, we calculate β according to equation (8) using the FX spot rate of the JPY against the USD, spot-forward spread, USD IRS rate, and JPY IRS rate. All of these variables are as of the New York closing time (5 p.m.) and obtained from Bloomberg. We use the midpoints of the observed bid-ask quotes. Maturities are from one year to five years. Both α and β are denominated in percentage points. The sample period is from July 1, 1997 to November 30, 2006, and the number of observations is 2,458.

Figure 4 plots α and β and Table 1 reports summary statistics of α and β . From these, we find that regardless of maturity: (i) means of both α and β are negative; (ii) means of β

are smaller than those of α ; and (iii) β is more volatile in terms of standard deviations than α . Recall that the conventional no-arbitrage condition that does not allow for differential risk premiums predicts that α and β should be zero. Hence, consistently negative α and β indicate the violation of the conventional no-arbitrage condition. We have already proved that this is not the case if we allow for differential risk premiums that have actually been observed in the markets. Table 2 reports the result of the Augmented Dickey-Fuller (ADF) test and shows that α and β are found to be I(1) at the 5% significance level except three-year β .

5. Structural Models of Price Discovery

Price discovery is the process defined by Lehmann [2002] as the efficient and timely incorporation of information implicit in investor trading into market prices. When the same fundamentals are priced into two markets, order flow is fragmented and price discovery is split between these markets. In this paper, we adopt the following three structural models, which, among others, are extensively investigated in the literature.

5.1 Baseline Model

$$\alpha_t = m_t + s_{\alpha,t} \quad s_{\alpha,t} \sim N(0, \sigma_{s\alpha}^2) \quad (11)$$

$$\beta_t = m_t + s_{\beta,t} \quad s_{\beta,t} \sim N(0, \sigma_{s\beta}^2) \quad (12)$$

$$m_t = m_{t-1} + \xi_t \quad \xi_t \sim N(0, \sigma_{\xi}^2) \quad (13)$$

This model is similar to the structural-form model used in Lehmann [2002]. Here, there is an unobservable efficient price m_t that follows a random-walk process, which is common to both swap prices.¹⁸ The random-walk representation of the efficient price dates back to Samuelson [1965], who shows that realised changes in prices observed in informationally efficient markets are not forecastable given the current information set by the Law of Iterated Expectations. The parameters in the state space model are estimated by maximising the log likelihood that can be evaluated using the Kalman filter.¹⁹ Throughout the paper, we assume that each residual is mutually independent.

In this setting, we calculate the following “signal-to-noise” measures to assess price discovery statistically, defined as the share of efficient price volatility in the total volatility for each swap price:²⁰

¹⁸ Another popular specification is the local linear trend specification proposed in Harvey [1989]:

$$m_t = m_{t-1} + \delta_{t-1} \\ \delta_t = \delta_{t-1} + \omega_t \quad \omega_t \sim N(0, \sigma_{\omega}^2),$$

where the efficient price m_t is a random-walk process with a stochastic drift δ_t . We also used this specification, but found that the estimated δ_t is not significantly different from zero. Hence, we did not choose this specification.

¹⁹ For details of the state space models, see Durbin and Koopman [2001], for instance.

²⁰ The conventional definition of the signal-to-noise ratio is the ratio of efficient price volatility to stochastic noise volatility. We use this form of the signal-to-noise ratio mainly for ease of interpretation.

$$\text{SIS}_\alpha^{(1)} = \frac{\sigma_\xi^2}{\sigma_\xi^2 + \sigma_{s\alpha}^2} \quad \text{and} \quad \text{SIS}_\beta^{(1)} = \frac{\sigma_\xi^2}{\sigma_\xi^2 + \sigma_{s\beta}^2} . \quad (14)$$

We call this measure the structural information share (SIS) in this paper. In what follows, we conduct the Wald test to assess whether these two measures are significantly different from each other.

5.2 Partial Adjustment Model

$$\alpha_t = C_\alpha m_t + (1 - C_\alpha) \alpha_{t-1} + s_{\alpha,t} \quad s_{\alpha,t} \sim N(0, \sigma_{s\alpha}^2) \quad (15)$$

$$\beta_t = C_\beta m_t + (1 - C_\beta) \beta_{t-1} + s_{\beta,t} \quad s_{\beta,t} \sim N(0, \sigma_{s\beta}^2) \quad (16)$$

$$0 < C_\alpha, C_\beta \leq 2$$

$$m_t = m_{t-1} + \xi_t \quad \xi_t \sim N(0, \sigma_\xi^2) \quad (17)$$

This model is a partial adjustment model similar to the model proposed in Amihud and Mendelson [1987] and Hasbrouck and Ho [1987]. $0 < C_i < 1$ represents the case of partial price adjustment, with $C_i = 0$ and $C_i = 1$ as special cases of no price reaction to the efficient price and complete price adjustment, respectively. Note also that we do not exclude the case of overreaction or overshooting of prices given new fundamental information, which corresponds to $1 < C_i \leq 2$. In this setting, our structural information shares can be written as

$$\text{SIS}_\alpha^{(2)} = \frac{C_\alpha^2 \sigma_\xi^2}{C_\alpha^2 \sigma_\xi^2 + \sigma_{s\alpha}^2} \quad \text{and} \quad \text{SIS}_\beta^{(2)} = \frac{C_\beta^2 \sigma_\xi^2}{C_\beta^2 \sigma_\xi^2 + \sigma_{s\beta}^2} . \quad (18)$$

5.3 Under/Overreaction Model

$$\alpha_t = m_t + D_\alpha (m_t - m_{t-1}) + s_{\alpha,t} \quad s_{\alpha,t} \sim N(0, \sigma_{s\alpha}^2) \quad (19)$$

$$\beta_t = m_t + D_\beta (m_t - m_{t-1}) + s_{\beta,t} \quad s_{\beta,t} \sim N(0, \sigma_{s\beta}^2) \quad (20)$$

$$m_t = m_{t-1} + \xi_t \quad \xi_t \sim N(0, \sigma_\xi^2) \quad (21)$$

This model also allows for possible under- or overreaction to new fundamental information, as emphasised by Amihud and Mendelson [1987]. This model is actually used by Menkveld, Koopman, and Lucas [2007] to investigate round-the-clock price discovery for cross-listed stocks. Here, significantly positive (negative) D_i indicates overreaction (underreaction) to fundamental information. In this case, structural information shares can be written as

$$\text{SIS}_\alpha^{(3)} = \frac{(1 + D_\alpha)^2 \sigma_\xi^2}{(1 + D_\alpha)^2 \sigma_\xi^2 + \sigma_{s\alpha}^2} \quad \text{and} \quad \text{SIS}_\beta^{(3)} = \frac{(1 + D_\beta)^2 \sigma_\xi^2}{(1 + D_\beta)^2 \sigma_\xi^2 + \sigma_{s\beta}^2} . \quad (22)$$

6. Empirical Results

6.1 Estimation Results of Structural Models

Tables 3-5 report the estimation results for each state space model. In estimation, we added a constant term in the equation of α to adjust for the possible differences in institutional factors, including transaction costs between α and β . First, Table 3 shows the result for the baseline model. All the variance coefficients and the constant term are significant at the 1% level. Estimated constant terms are within the range of 5-9 basis points, which is broadly consistent with anecdotal evidence of transaction costs. The structural information shares are much larger for α than for β , and $SIS_{\alpha}^{(1)}$ is found to be significantly higher than $SIS_{\beta}^{(1)}$ at the 1% level for all the maturities.

Second, Table 4 shows the result for the partial adjustment model. All the coefficients are significantly estimated at the 1% level. The adjustment coefficients for α except one-year maturity are not significantly different from one, suggesting that the currency swap price α reflects the efficient price almost completely. On the other hand, those for β are within the range of 0.3-0.6. Consistent with these findings, the structural information share for α is significantly higher than that for β at the 1% level.

Third, Table 5 shows the result for the under/overreaction model. Here, the under/overreaction coefficients for α are not significant from zero for all the maturities, suggesting that α shows an almost exact response to the efficient price changes. On the other hand, those for β are significantly negative for all the maturities. This suggests that β tends to underreact to the efficient price changes in a statistical sense, although the level of parameter estimates is not high in an economic sense. Consistent with this result, the structural information shares significantly favour α over β .

In sum, all of the results from the three model specifications show that the currency swap price α has a significantly more important price discovery role than the FX swap price β for all the maturities.²¹ α almost exactly reacts to the efficient price changes, but β tends to underreact to them. Figure 5 shows the efficient prices we estimated as the filtered state variables from these models.²² Each estimated efficient price should capture the permanent component of prices for the economic function of exchanging USD for JPY. More intuitively, it should reflect the fundamental price of the demand for USD relative to JPY in these swap markets that would prevail in the absence of microstructural noises. Here, the negative efficient price shows that fundamental demand is higher for USD than for JPY in those markets. From this figure, we can see a very similar movement of the efficient price regardless of the model specifications.

²¹ Since the second and third models encompass the first model, we checked the relative validity of the models using the likelihood ratio (LR) test, and found that the second model is superior to the first for all maturities while the third is found not to be superior to the first.

²² We used the Kalman filtering algorithm instead of the Kalman smoothing algorithm. Since the Kalman filtering algorithm is a forward recursion that computes one-step-ahead estimates of the state variables, it seems more suitable for expressing the dynamic process of incorporating new information into market prices. On the other hand, the Kalman smoothing algorithm is a backward recursion based on the full data.

6.2 Robustness Check: Reduced-Form Analysis

As an attempt to check the robustness of the above estimation results, we also estimate the price discovery measures based on the reduced-form approach. There are two approaches that have attracted academic attention in this regard. One is the permanent-transitory (PT) model developed by Gonzalo and Granger [1995], and the other is the information share (IS) model developed by Hasbrouck [1995]. Both models rely on estimation of the VECM of market prices.

The PT model decomposes the common factor itself and attributes superior price discovery to the market that adjusts least to price movements in the other market. Meanwhile, the IS model decomposes the variance of the common factor based on the assumption that price volatility reflects new information flows, and hence the market that contributes most to the variance of the innovations to the common factor is considered to contribute most to price discovery.²³

Table 6 reports the result of the cointegration test and the corresponding price discovery measures for the PT and IS models. First, Table 6(i) shows that both Johansen trace and maximum eigenvalue tests suggest the significant existence of one cointegrating vector between α and β for each maturity at least at the 5% level. Second, Table 6(ii) shows that both the PT and IS measures of price discovery are very close to one, which means that the currency swap price has a significantly more important price discovery role than the FX swap price. Hence, the result for the reduced-form model confirms our findings from the structural models.

7. Concluding Remarks

This paper has investigated the relative role of price discovery between two long-term swaps that exchange the USD for JPY: the cross-currency (basis) swap and the FX swap. First, we have shown that we should consider differential risk premiums, observed particularly between the JPY and USD markets for the same bank group, to explain negative prices of these two swaps using the no-arbitrage argument.

Second, we have empirically investigated the relative role of price discovery using three structural models. Our main findings are that: (i) the efficient prices extracted as a common factor of the two swaps show a very similar movement, regardless of model specifications; (ii) the cross-currency swap market plays a much more dominant price discovery role than the FX swap market; and (iii) cross-currency swap prices react almost entirely to changes in the efficient price, while FX swap prices tend to underreact to them. These results are broadly consistent with the perceptions held by market participants.

²³ See Appendix for more details of each model.

References

- Amihud, Y., and H. Mendelson [1987], "Trading Mechanisms and Stock Returns: An Empirical Investigation," *Journal of Finance*, 42, pp. 1-30.
- Baba, N., M. Nakashima, Y. Shigemitsu, and K. Ueda [2006], "The Bank of Japan's Monetary Policy and Bank Risk Premiums in the Money Market," *International Journal of Central Banking*, 2, pp. 105-135.
- Baba, N., F. Packer, and T. Nagano [2008], "The Spillover of Money Market Turbulence to FX Swap and Cross-Currency Swap Markets," *BIS Quarterly Review*, March.
- Baillie, R., G. Booth, Y. Tse, and T. Zobotina [2002], "Price Discovery and Common Factor Models," *Journal of Financial Markets*, 5, pp. 309-321.
- Covrig, V., B. S. Low, and M. Melvin [2004], "A Yen is Not a Yen: TIBOR/LIBOR and the Determinants of the Japan Premium," *Journal of Financial and Quantitative Analysis*, 39, pp. 193-208.
- Durbin, J., and S. J. Koopman [2001], *Time Series Analysis by State Space Models*, Oxford, Oxford University Press.
- Engle, R., and C. Granger [1987], "Cointegration and Error-correction Representation, Estimation and Testing," *Econometrica*, 55, pp. 251-276.
- Fletcher, D., and J. Sultan [1997], "Cross Currency Swap Rates and Deviations from Interest Rate Parity," *Journal of Financial Engineering*, 6, pp. 47-69.
- Fletcher, D., and L. W. Taylor [1994], "A Non-parametric Analysis of Covered Interest Parity in Long-date Capital Markets," *Journal of International Money and Finance*, 13, pp. 459-475.
- Fletcher, D., and L. W. Taylor [1996], "Swap Covered Interest Parity in Long-Date Capital Market," *Review of Economics and Statistics*, 78, pp. 530-538.
- Gonzalo, J., and C. Granger [1995], "Estimation of Common Long-memory Components in Cointegrated Systems," *Journal of Business and Economic Statistics*, 13, pp. 27-35.
- Harvey, A. C. [1989], *Forecasting, Structural Time Series Models and the Kalman Filter*, Cambridge, Cambridge University Press.
- Hasbrouck, J., and T. S. Y. Ho [1987], "Order Arrival, Quote Behavior, and the Return-Generating Process," *Journal of Finance*, 42, pp. 1035-1048.
- Hasbrouck, J. [1995], "One Security, Many Markets: Determining the Contributions to Price Discovery," *Journal of Finance*, 50, pp. 1175-1199.
- Ito, T., and K. Harada [2000], "Japan Premium and Stock Prices: Two Mirrors of Japanese Banking Crises," NBER Working Paper Series No. 7997.
- Lehmann, B. [2002], "Some Desiderata for the Measurement of Price Discovery Across Markets," *Journal of Financial Markets*, 5, pp. 259-276.
- Menkveld, A. J., S. J. Koopman, and A. Lucas [2007], "Modelling Round-the-Clock Price Discovery for Cross-listed Stocks using State Space Methods," *Journal of Business and Economic Statistics*, 25, pp. 213-225.
- Nishioka, S., and N. Baba [2004], "Negative Interest Rates under the Quantitative Monetary Easing Policy in Japan: The Mechanism of Negative Yen Funding Costs in the FX Swap Market," Bank of Japan Working Paper No. 04-E-8, Bank of Japan.
- Ng, S., and P. Perron [2001], "Lag Length Selection and the Construction of Unit Root Tests with Good Size and Power," *Econometrica*, 69, pp. 1519-1554.

Peek, J., and E. S. Rosengren [2001], "Determinants of the Japan Premium: Actions Speak Louder than Words," *Journal of International Economics*, 53, pp. 283-305.

Popper, H. [1993], "Long-term Covered Interest Parity: Evidence from Currency Swaps," *Journal of International Money and Finance*, 12, pp. 439-448.

Samuelson, P. [1965], "Proof that Properly Anticipated Prices Fluctuate Randomly," *Industrial Management Review*, 6, pp. 41-49.

Takezawa, N. [1995], "Currency Swaps and Long-term Covered Interest Parity," *Economics Letters*, 49, pp. 181-185.

Yan, B., and E. Zivot [2006], "A Structural Analysis of Price Discovery Measure," Department of Economics, University of Washington.

Appendix: Reduced-Form Approach to Price Discovery

The reduced-form approach starts by estimating the following conventional VECM:

$$\Delta\alpha_t = \lambda_1(\alpha_{t-1} - \omega\beta_{t-1} - C) + \sum_{j=1}^p g_{1j}\Delta\alpha_{t-j} + \sum_{j=1}^p h_{1j}\Delta\beta_{t-j} + \varepsilon_{1t} \quad (\text{A1})$$

$$\Delta\beta_t = \lambda_2(\alpha_{t-1} - \omega\beta_{t-1} - C) + \sum_{j=1}^p g_{2j}\Delta\alpha_{t-j} + \sum_{j=1}^p h_{2j}\Delta\beta_{t-j} + \varepsilon_{2t}, \quad (\text{A2})$$

where $\alpha_{t-1} - \omega\beta_{t-1} - C$ denotes the error correction term, and ε_{1t} and ε_{2t} are i.i.d. shocks.

Based on the VECM above, the PT model decomposes the common factor itself and attributes superior price discovery to the market that adjusts least to price movements in the other market. As stated in Engle and Granger [1987], the existence of cointegration ensures that at least one market has to adjust. Price discovery for the first market can be measured by

$$PT = \frac{\lambda_2}{\lambda_2 - \lambda_1} \quad (\text{A3})$$

in the Gonzalo and Granger model.

On the other hand, the IS model decomposes the variance of the common factor based on the assumption that price volatility reflects new information flows. Hence, the market that contributes most to the variance of the innovations to the common factor is considered to contribute most to price discovery. Price discovery for the first market can be measured as

$$IS_1 = \frac{\lambda_2^2 \left(\sigma_1^2 - \frac{\sigma_{12}^2}{\sigma_2^2} \right)}{\lambda_2^2 \sigma_1^2 - 2\lambda_1 \lambda_2 \sigma_{12} + \lambda_1^2 \sigma_2^2} \quad \text{and} \quad IS_2 = \frac{\left(\lambda_2 \sigma_1 - \lambda_1 \frac{\sigma_{12}}{\sigma_1} \right)^2}{\lambda_2^2 \sigma_1^2 - 2\lambda_1 \lambda_2 \sigma_{12} + \lambda_1^2 \sigma_2^2}, \quad (\text{A4})$$

where σ_1^2 , σ_2^2 and σ_{12} are factors in the covariance matrix of ε_{1t} and ε_{2t} . Note here that IS_1 and IS_2 measure the lower and upper bounds of Hasbrouck's measure of price discovery, where the difference between these two bounds is positively related to the degree of correlation between residuals.²⁴ Baillie *et al.* [2002] argue that the average of these two bounds provides a sensible estimate of price discovery when the data frequency is high. Also note here that PT ignores the correlation between the markets and hence if the residuals are strongly correlated, then both models can provide substantially different results.²⁵

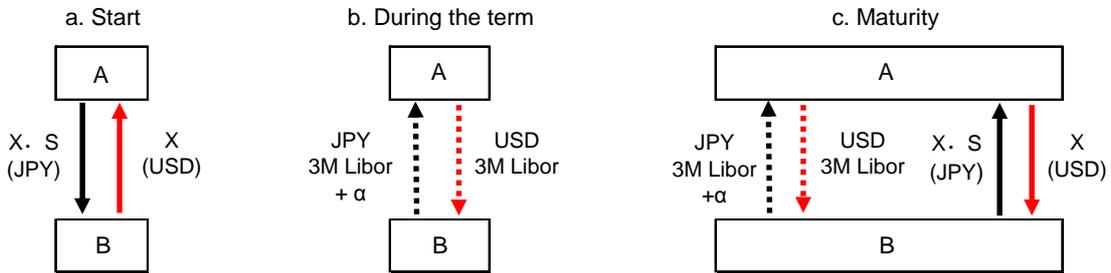
²⁴ When the residuals are not correlated – that is, the variance-covariance matrix of residuals is diagonal – the information share is identified. When, conversely, the residuals are correlated, it is not identified because the result depends on the ordering of variables in the Cholesky factorisation of the variance-covariance matrix. Hence, all one can do is compute the lower and upper bounds.

²⁵ Yan and Zivot [2006] rigorously analyse the determinants of these two price discovery measures in some structural model settings, in which both permanent and transitory shocks are identified, and the correlation between residuals from the VECM and each fundamental and transitory shock are explicitly taken into consideration. As a result, they find some inconsistency in the interpretation of these two price discovery measures based on the reduced-form approach.

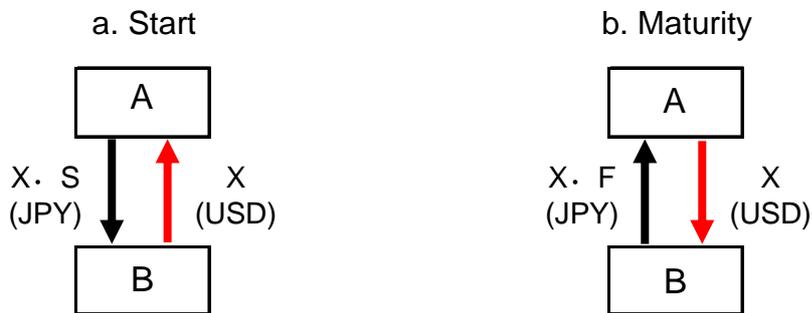
Figure 1

Basic schemes of the cross-currency basis swap and FX swap

(i) Cross-currency basis swap



(ii) FX Swap



S : FX spot rate (JPY/USD)

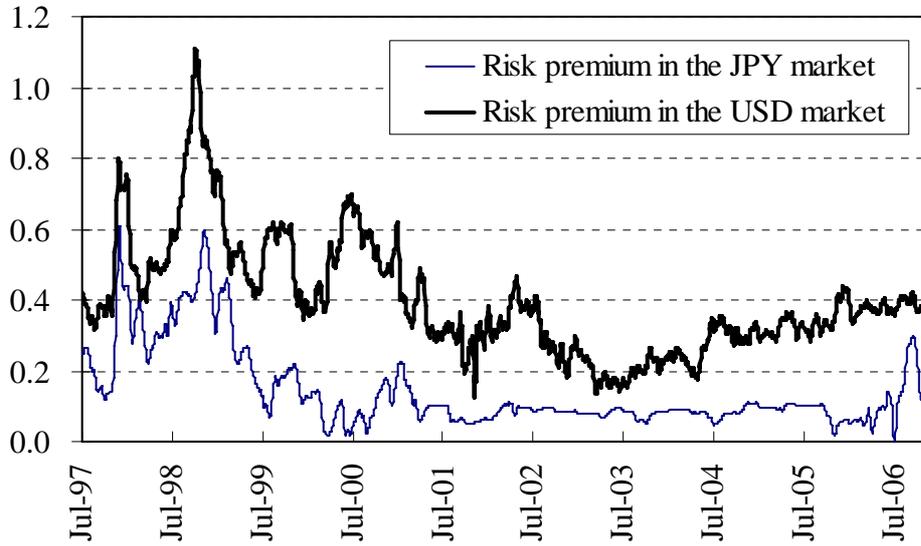
F : FX forward rate (JPY/USD)

Figure 2

Differential risk premiums between USD and JPY markets

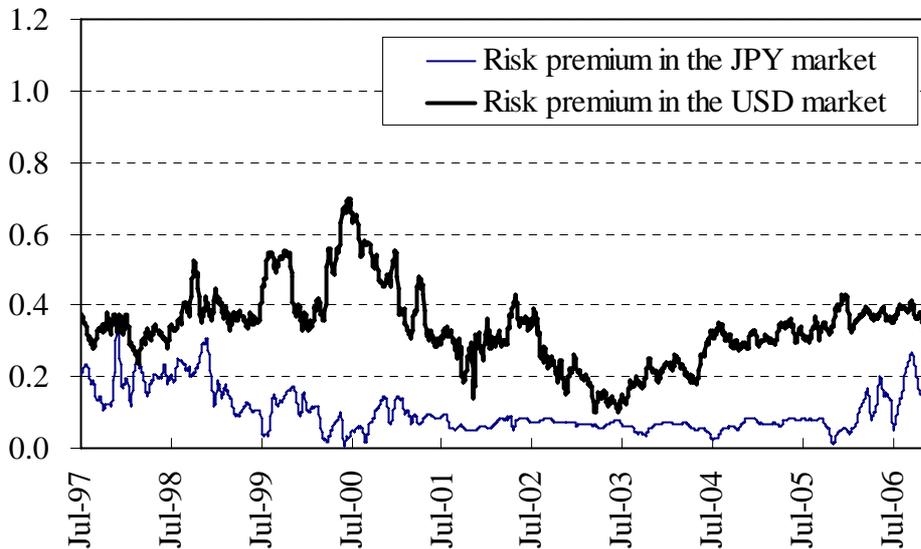
(i) Risk premium for Japanese banks

(%)



(ii) Risk premiums for non-Japanese banks

(%)

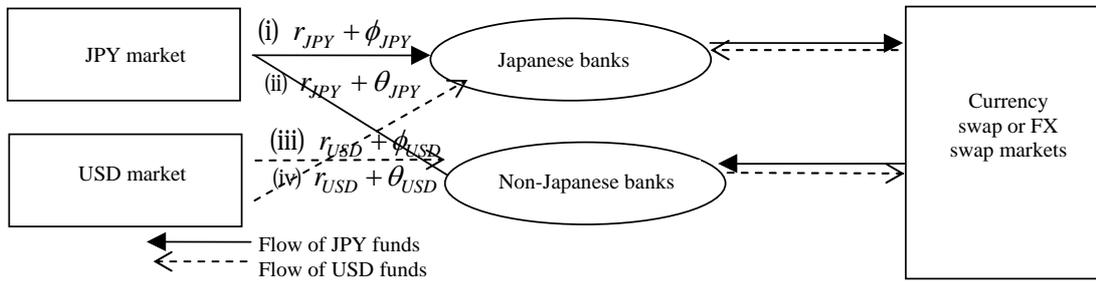


Notes: 1 Risk premiums for Japanese banks in the USD (JPY) markets are calculated as one-year USD-TIBOR (JPY-TIBOR) minus yields on one-year U.S. (Japanese) government bonds. Risk premiums for non-Japanese banks in the USD (JPY) markets are calculated as one-year USD-LIBOR (JPY-LIBOR) minus yields on one-year U.S. (Japanese) government bonds. 2 The data shown above is the 10-day moving average of the original data.

Source: Bloomberg.

Figure 3

Typical funding structure of Japanese and non-Japanese banks



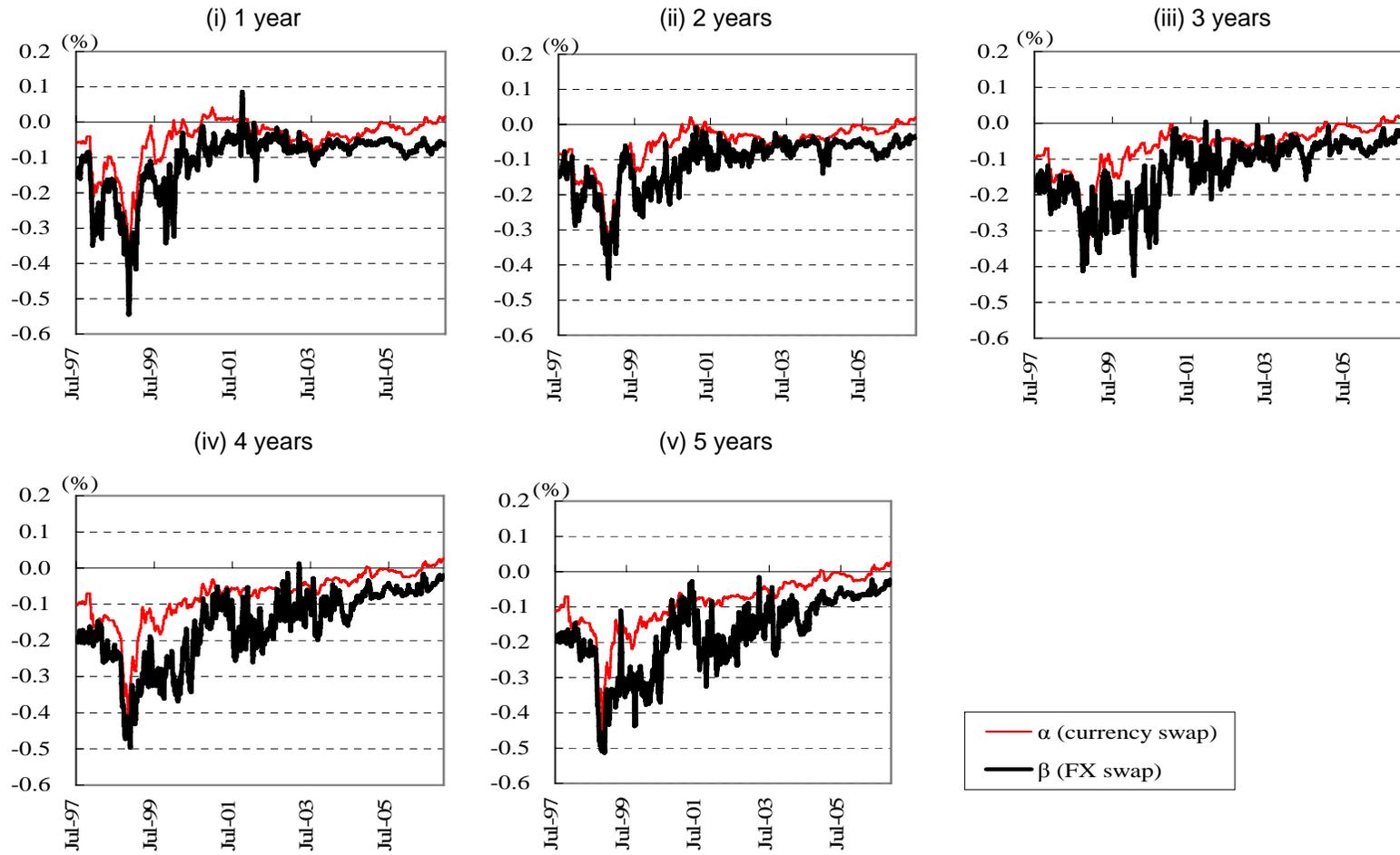
$r_{JPY}(r_{USD})$: JPY(USD) reference interest rate

$\phi_{JPY}(\phi_{USD})$: Risk premium for Japanese banks in the JPY(USD) market

$\theta_{JPY}(\theta_{USD})$: Risk premium for non-Japanese banks in the JPY(USD) market

Figure 4

Time-Series Movement of α and β



Note: The data shown above is the 10-day moving average of the original data.

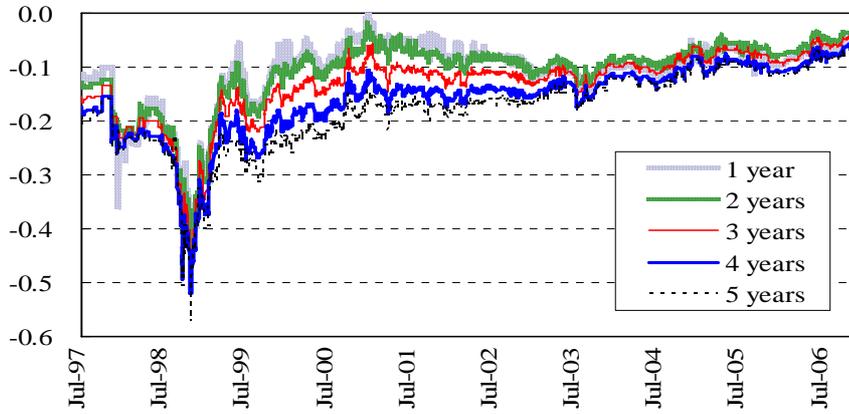
Source: Bloomberg.

Figure 5

Efficient prices extracted from each structural model

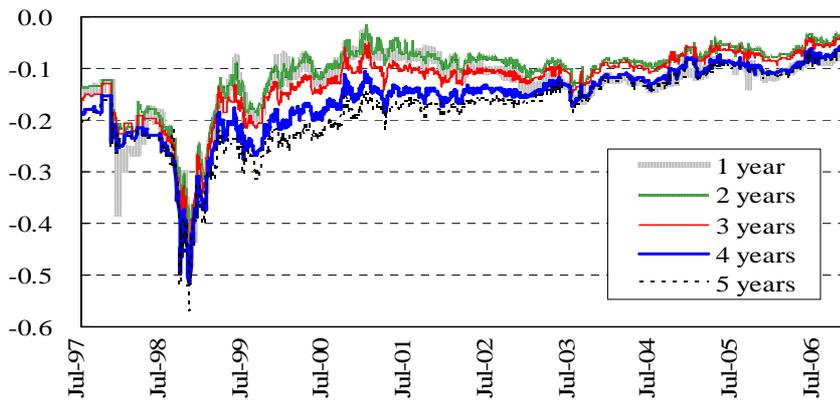
(i) Baseline model

(%)



(ii) Partial Adjustment Model

(%)



(iii) Under/Overreaction Model

(%)

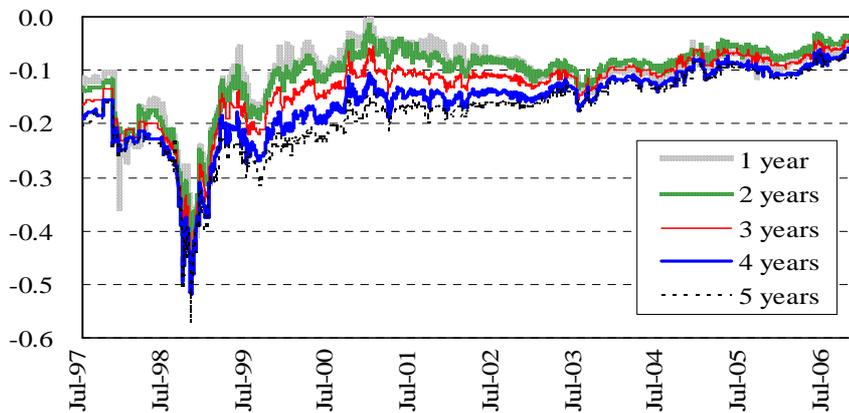


Table 1

Summary statistics

Sample period (daily): July 1, 1997 to November 30, 2006 (number of observations: 2,458)

Maturity		Mean	Std. dev.	Maximum	Minimum
1 year	α	-0.048	0.066	0.060	-0.380
	β	-0.109	0.095	0.308	-0.775
2 years	α	-0.058	0.066	0.038	-0.405
	β	-0.109	0.086	0.202	-0.588
3 years	α	-0.066	0.067	0.028	-0.420
	β	-0.131	0.109	0.336	-0.667
4 years	α	-0.076	0.071	0.031	-0.435
	β	-0.160	0.116	0.405	-0.688
5 years	α	-0.087	0.076	0.033	-0.480
	β	-0.178	0.123	0.143	-0.852

Table 2

Unit root test

Sample period (daily): July 1, 1997 to November 30, 2006 (number of observations: 2,458)

		Augmented Dickey-Fuller test	
Maturity		Level	1 st difference
1 year	α	-2.368	-56.066**
	β	-2.812	-73.151**
2 years	α	-1.744	-24.887**
	β	-2.522	-75.445**
3 years	α	-1.950	-12.140**
	β	-2.960*	-75.989**
4 years	α	-1.683	-23.965**
	β	-1.995	-75.472**
5 years	α	-1.636	-24.299**
	β	-2.136	-76.084**

Notes: 1 * and ** denote significance at the 5% and 1% level, respectively. Test statistics are based on the specification with a constant term. 2 The number of lags is chosen by the modified AIC by Ng and Perron [2001].

Table 3

Baseline model

Sample period (daily): July 1, 1997 to November 30, 2006 (number of observations: 2,458)

	<i>i</i>	1 year	2 years	3 years	4 years	5 years
$\ln \sigma_i^2$	s_α	-11.393** [0.053]	-11.299** [0.048]	-11.581** [0.031]	-11.675** [0.018]	-11.689** [0.016]
	s_β	-5.637** [0.003]	-5.660** [0.018]	-4.874** [0.012]	-5.070** [0.018]	-4.949** [0.018]
	ξ	-9.830** [0.002]	-10.345** [0.026]	-10.380** [0.016]	-10.356** [0.011]	-10.287** [0.010]
Constant		0.061** [0.001]	0.052** [0.001]	0.065** [0.002]	0.084** [0.002]	0.091** [0.002]
Log likelihood		11,656	12,178	11,299	11,524	11,225
$SIS_\alpha^{(1)}$		0.827	0.722	0.769	0.789	0.803
$SIS_\beta^{(1)}$		0.015	0.009	0.004	0.005	0.005
$SIS_\alpha^{(1)} - SIS_\beta^{(1)}$		0.812** [0.010]	0.713** [0.014]	0.765** [0.008]	0.784** [0.004]	0.798** [0.004]

Notes: 1 The figures in square brackets are standard errors. * and ** denote significance at the 5% and 1% level, respectively. 2 The Wald test is conducted to test the difference between SIS_α and SIS_β . 3. Constant denotes the constant term in the α equation.

Table 4

Partial adjustment model

Sample period (daily): July 1, 1997 to November 30, 2006 (number of observations: 2,458)

	<i>i</i>	1 year	2 years	3 years	4 years	5 years
C_i	α	0.929** [0.015]	1.025** [0.052]	1.010** [0.012]	1.018** [0.066]	1.000** [0.004]
	β	0.343** [0.004]	0.569** [0.012]	0.588** [0.009]	0.572** [0.014]	0.568** [0.013]
$\ln \sigma_i^2$	s_α	-10.965** [0.034]	-12.403** [0.497]	-12.718** [0.152]	-12.000** [0.509]	-12.948** [0.001]
	s_β	-6.290** [0.008]	-5.921** [0.001]	-5.294** [0.004]	-5.281** [0.017]	-5.147** [0.019]
	ξ	-9.372** [0.015]	-10.451** [0.024]	-10.332** [0.011]	-10.256** [0.024]	-10.217** [0.011]
Constant		0.078** [0.003]	0.052** [0.003]	0.065** [0.002]	0.085** [0.006]	0.091** [0.003]
Log likelihood		12,106	12,352	11,487	11,769	11,428
$SIS_\alpha^{(2)}$		0.831	0.876	0.917	0.851	0.939
$SIS_\beta^{(2)}$		0.044	0.011	0.002	0.007	0.006
$SIS_\alpha^{(2)} - SIS_\beta^{(2)}$		0.787** [0.003]	0.865** [0.056]	0.915** [0.013]	0.844** [0.067]	0.933** [0.001]

Notes: 1 The figures in square brackets are standard errors. * and ** denote significance at the 5% and 1% level, respectively. 2 The Wald test is conducted to test the difference between SIS_α and SIS_β . 3 Constant denotes the constant term in the α equation.

Table 5

Under/overreaction model

Sample period (daily): July 1, 1997 to November 30, 2006 (number of observations: 2,458)

	<i>i</i>	1 year	2 years	3 years	4 years	5 years
$D_i \times 10^5$	α	-0.001 [0.002]	-0.001 [0.020]	0.000 [0.037]	0.043 [0.170]	0.011 [1.618]
	β	-99.940** [0.200]	-45.212** [5.896]	-152.7** [0.001]	-48.636** [0.779]	-62.091** [6.582]
$\ln \sigma_i^2$	s_α	-11.436** [0.056]	-11.314** [0.001]	-11.736** [0.032]	-11.710** [0.038]	-11.385** [0.035]
	s_β	-5.654** [0.001]	-5.709** [0.017]	-4.870** [0.002]	-5.071** [0.002]	-4.957** [0.002]
	ξ	-9.805** [0.015]	-10.412** [0.015]	-10.395** [0.015]	-10.272** [0.016]	-10.237** [0.016]
Constant		0.061** [0.003]	0.052** [0.001]	0.065** [0.002]	0.084** [0.002]	0.091** [0.002]
Log likelihood		11,657	12,180	11,300	11,524	11,227
$SIS_\alpha^{(3)}$		0.836	0.711	0.793	0.809	0.810
$SIS_\beta^{(3)}$		0.016	0.009	0.004	0.005	0.005
$SIS_\alpha^{(3)} - SIS_\beta^{(3)}$		0.821** [0.010]	0.702** [0.003]	0.789** [0.007]	0.803** [0.008]	0.805** [0.007]

Notes: 1 The figures in square brackets are standard errors. * and ** denote significance at the 5% and 1% level, respectively. 2 The Wald test is conducted to test the difference between SIS_α and SIS_β . 3 Constant denotes the constant term in the α equation.

Table 6

Reduced-form model**(i) Johansen cointegration test**

Sample period (daily): July 1, 1997 to November 30, 2006 (number of observations: 2,458)

Maturity	Number of cointegrating vectors			
	Trace test		Maximum eigenvalue test	
	None	At most 1	None	At most 1
1 year	22.25*	5.49	16.75*	5.49
2 years	24.13*	4.22	19.90*	4.22
3 years	20.71*	4.18	16.53*	4.18
4 years	45.01**	3.11	41.90**	3.11
5 years	25.11*	2.39	22.72**	2.39

(ii) Price discovery measures

Maturity	PT		IS	
		Lower	Upper	
1 year	0.97	0.94	0.97	
2 years	0.96	0.88	0.93	
3 years	0.98	0.93	0.95	
4 years	0.99	0.99	0.99	
5 years	0.99	0.99	0.99	

Notes: 1 * and ** denote significance at the 5% and 1% level, respectively. The restriction on the cointegrating vector is tested by applying the likelihood ratio test. 2 The number of lags is chosen by AIC.