ESSAYS ON INTEREST RATE SWAP DYNAMICS

by

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Abstract

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This dissertation consists of three essays covering the dynamics of interest rate swaps. The first essay investigates the potential determinants of swap spreads. The fundamental question is whether *liquidity* or *credit* dominates the stochastic evolution of swap spreads. Significant, negative impacts from liquidity on swap spreads are found, which agrees with the prevailing view among swap traders that the swap spread serves mainly as an indicator of "market liquidity". The results also indicate that the importance of credit risk in valuing swap contracts subsides from the mid-1990s. Market volatility seems to play a relatively minor role in this setting.

In the second essay, the temporal relationship between US interest rate swap spreads, US corporate credit spreads, LIBOR and the shape of the Treasury yield curve is explored by performing cointegration tests and estimating an error correction model. One cointegrating relationship is detected, implying that a single common factor must underlie the time series behaviors of these variables and a stable long-run linear relationship exists among them. In addition, the cointegrating vector emerged from the regression documents complex dynamics between the swap and the equity markets in

the US.

The linkage between the USD and HKD swap curves is examined in the third essay. It is argued that these curves contain important information, which is over and above that provided by the sovereign yield curves and the standard measures of market liquidity, LIBOR-type interest rates. The study shows that using sovereign yield curves and concentrating only on the risk premium associated with the breakdown of the currency peg is not sufficient for policy making in Hong Kong. Swap spreads and swap curves should be carefully monitored to evaluate economy wide risks and to conduct macroeconomic policy.

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Chapter 1

Introduction

The interest rate swaps market is one of the largest components of the global derivatives markets and a natural adjunct to the fixed income markets. Understanding the over-the-counter (OTC) swaps market can provide a deeper insight into the capital flows that drive the bond markets, the way in which companies manage their exposure to fluctuations in interest rates and the way financial institutions make a great deal of their income. Indeed, the swap curve is emerging as the preeminent benchmark yield curve, against which even some government bonds are often referenced.

Since its inception in the early 1980s, the swap market has expanded rapidly into a multi-trillion dollar market. Total outstanding interest rate swaps currently exceed 95 trillion dollars in notional principal amount, being the largest single group of products in the OTC derivatives market. US dollar denominated transactions account for roughly 29% of all interest rate swaps outstanding.

In substance, an interest rate swap is a negotiated contractual agreement between two parties to exchange a series of interest payments for a stated period of time. Typically, one party will make fixed rate payments while the other makes floating rate payments on the same notional principal amount, but with only the net cash flows exchanged. This type of plain vanilla product is what the dissertation focuses on. Three aspects of the dynamics of interest rate swaps are examined. The first essay attempts to shed new light on the key factors explaining the swap spread, which is the margin above the underlying treasury where the swap rate is set. To the extent that any interest rate swap involves mutual obligations to exchange cash flows, a degree of credit risk must be implicit in the swap. In a similar vein, the level of liquidity in the financial markets and the market volatility contribute to the risk premium in the swap spread. Using recent daily data, the study employs proxies for credit, liquidity and volatility and shows the dominant role of liquidity in determining swap spreads since the mid 1990s.

Efforts are taken in the second essay to look at the cointegration issue among swap spreads and a set of fixed income market variables. Evidence is found for exactly one cointegrating relationship and an error correction model is estimated, disentangling the relative importance of lagged innovations in the variables, as well as deviations of the variables from their long-run cointegrating relationship, to innovations in the ten-year swap spread. It is noteworthy that the cointegrating vector found suggests a complex linkage between the swap market and the Nasdaq market.

It is well known that, as HKD is pegged to USD under a currency board system, the HKD and USD interest rates should be the same and should at least move in tandem. But in reality, the difference of the two interest rates changes over time, mainly reflecting the market confidence on the peg and perhaps other local complexities. Given this background, the paramount concern in the third essay is to investigate what kind of HK interest rate best reflects the time varying departure of HKD interest rates from the USD ones. It is argued that the HKD swap interest rates contain important information over and above that provided by the Hong Kong government debt (exchange fund bills and notes) because the swap market is much more liquid and provides better pricing information about local demand and supply. The study also shows what kind of USD interest rates is more relevant to the HKD interest rate dynamics. Empirical tests are run and the results turn out to be consistent with the proposed hypotheses. The implication of the findings to the monetary policy making of the Hong Kong Monetary Authority (HKMA) is suggested in the end.

Chapter 2

What Drives Swap Spreads, Credit or Liquidity?

2.1 Introduction

Swap spreads[1] have been playing a crucial role in the financial market, since they are becoming a closely watched indicator of the market's view of macroeconomic risk. Understanding and predicting swap spreads is an important exercise, given the swap trading volume of trillions of dollars (notional) annually, and their extensive use by corporations and financial institutions for risk management as well as speculations. Furthermore, swap spreads have been significantly affected by government efforts to manage national debt, as Ministries of Finance from France to Germany have started adjusting their debt profile through swaps. Although the question about the determinants of interest rate swap spreads has attracted increasing attention, the existing empirical literature is much smaller than the one in theoretical models.

At the outset, mainly two broad measurement criteria are used to interpret swap spreads. First, they can be viewed as an "effective proxy for banking liquidity".[2] This interpretation is consistent with the formal derivation of the swap rate as an average (under the appropriate *forward measure*) of future LIBOR rates (London Inter Bank Offered Rate). A second interpretation of swap spreads is that they are mostly a proxy for the AA- credit spreads, although often this is contradicted in reality by the spreads paid by AAA rated borrowers such as Fannie Mae.

One objective of this study is to achieve a better understanding of whether liquidity or credit (or both) accounts for the variations in swap spreads by utilizing

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[1] In the US, swap spreads are quoted simply as spreads over the comparable maturity treasuries.
[2] International Financing Review, June 29, 2002.

recent data. Most stylized facts about the potential forces that drive swap spreads diverge. According to Grinblatt (1995) the liquidity difference between one-month LIBOR and one-month Treasury bill yield alone can explain interest rate swap spreads very well. Credit spreads are assumed to have little impact on the swap spreads term structure and hence are not incorporated in his one-factor model.

Lang et al. (1998) use 10- and 5-year average swap spreads data to analyze the impact of the changes of the counterparty risk in swaps on swap spreads. They find that swap spreads increase if either single-A spreads (lower credit rated bond spreads) or agency spreads (higher credit rated bond spreads) increase. They also conclude that swap spreads contain procyclical element, and that the business cycle factor affects the default risk of single-A firms. However, their work is constrained by the fact that swap spreads are examined solely from the perspective of the bargaining power between counterparties over the swap surplus and of the business cycle element.

Counterparty default risk is simply assumed to be ignorable by He (2000), and he argues that a swap contract is essentially a Master Swap Agreement.[3] Using a multi-factor model, he concludes that swap spreads are equivalent to the present value of LIBOR over GC (General Collateral)-repo rates properly amortized over the swap maturity.

To date, a very limited amount of empirical work has been attempted to disentangle what drives swap spreads. The seminal paper dealing with this issue is Duffie and Singleton (1997). The empirical regressions in their paper intend to

[3] Comprehensive documentation of standard terms and conditions covering all swap transactions between two counterparties. Usually based on standard documents prepared by the International Swap and Derivatives Association (ISDA).

capture the swap spreads' own effect, the effects from risk-free rates, liquidity and credit risk. They reveal that the shocks to swap spreads per se can account for almost half of their own variations over two years, and that both corporate credit risk and liquidity have impact on swap zero spreads. Their findings also indicate that liquidity-repo effect and demands for the fixed leg of swaps contribute to the variation of swap spreads. "Credit effects are weak initially" but "increase in importance" over the longer horizon.

However, a very important variable seems to be missing from their work and others' in this strand of study — market volatility. In fact, today's swap market is subject to profoundly different dynamics compared with the market before the fall of 1998. It is seen that before August 1998, swap spreads had been fairly constant. During our sample period from November 1996 to March 2003,[4] the market has been beset by increased volatility due to major crises and events such as the Russian credit meltdown and the demise of LTCM in 1998, the Y2K liquidity problem in 1999, US Treasury buyback program in 2000 and the September 11 aftermath in 2001. Besides the more volatile movements observed in swap spreads during this period, the swap market has witnessed increasing use of collateralization, margining, netting and other measures to mitigate counterparty risk inherent in the swap market in the wake of financial crises of 1998. Another important feature standing out during this time span is that the US Government became more active in the swap market, and this may have dramatically changed the characteristic of the market. One could claim that swap spreads have become independent risk factors in their own right. These new phenomena make

[4] They use weekly data over the period from January 15, 1988 to October 2, 1994.

worthwhile our endeavor here to disentangle the effects from credit, liquidity and volatility in explaining the dynamics of swap spreads. In addition, using recent daily data permits us to, as expected, obtain much sharper results.

To test the potential factors that drive swap spreads and their relative importance, we draw on a vector autoregression model. The model is formulated to incorporate the time series dynamics of swap spreads, the swap term structure, TED (Treasury Eurodollar) spreads and the market volatility. Key empirical results are based on block exogeneity tests and innovation accounting analysis.

The rest of the chapter is organized as follows. We start with a theoretical framework for swaps in Section 2.2 and then review the major theoretical determinants of swap spreads in Section 2.3. Next, descriptions of the data set and the variables are given in Section 2.4, followed by a discussion of the swap spreads dynamics and regression results in Section 2.5. Finally we provide concluding remarks.

2.2 A Framework for Swaps

This section sets the terminology and derives the arbitrage-free value of a swap rate. We focus on *forward* fixed-payer interest rate swaps. These are vanilla products in the sense that the contracts are pre-designed, homogeneous, very liquid (the bid-ask spreads are very tight), and every market player is familiar with their properties. To illustrate, the fundamental features of swap transactions consist of:

- The notional amount is N, the tenor of the underlying LIBOR rate is 6 months.

- The swap matures at time T. The swap contract is signed at time t_0 but starts at time t_1, hence the term *forward* swap.
- The dates $\{t_i, i = 1, \dots, n - 1\}$ are *reset dates* where the relevant LIBOR rate, $\{Lt_i\}$ will be determined.[5] These dates are apart δ time units, with $\delta = 1/2$.
- The dates $\{t_i, i = 2, \dots, n\}$ are *settlement dates* where the LIBOR rates are used to exchange the floating cash flows δNLt_i against the fixed ones δNs_{to} at each t_{i+1}. s_{to} is the swap rate.

We need to define the default-free pure *discount bonds*. A buyer pays the current price $B(t_o, T_i)$ of these bonds at t_o to receive \$1 in the same currency at maturity dates $T_i = t_i$. Given that these bonds are default-free, the time t_i payoffs are *certain* and the price $B(t_o, T_i)$ can be considered as the value today of \$1 to be received at time t_i. This means they are in fact the relevant discount factors, or in market language simply *discounts* for t_i, since credit risk is assumed away. Note that as

$$T_1 < \cdots < T_n \tag{2.1}$$

bond prices must satisfy the following, regardless of the slope of the yield curve:[6]

$$B(t_o, T_1) > \cdots > B(t_o, T_n) \tag{2.2}$$

Hence, these bonds can be used to adjust to the *present*, values of various cash flows occurring at future settlement dates. They are likely to be quite useful in dealing with successive swap cash flows.

5 That is, determined by some objective and pre-defined authority such as the British Bankers Association.

6 If one shorts *one* longer term bond to fund a long position in *one* short term bond, one would not have enough money using discount bonds.

The third major component of the framework is a series of Forward Rate Agreements (FRA) paid-in-arrears. For each FRA, a floating (random) payment is made against a known (fixed) payment for a net payment of,

$$[L_{t_i} - F(t_o, t_i)]\, N\, \delta \qquad (2.3)$$

at times t_{i+1}. Here, the $F(t_o, t_i)$ denotes the forward rates.

2.2.1 Equivalence of Cash Flows

We now obtain a series of arbitrage relationships concerning swap rates. First, note that the FRA contracts imply a certain *equivalence*. There is a strip of floating cash flows:

$$\{N\, \delta\, L_{t_1}, \cdots, N\, \delta\, L_{t_{n-1}}\} \qquad (2.4)$$

and according to observed liquid prices, the market is willing to exchange these (random) cash flows against the known (fixed) cash flow:

$$\{N\, \delta\, F(t_o,t_1), \cdots, N\, \delta\, F(t_o,t_{n-1})\} \qquad (2.5)$$

This means something important. If the markets in these FRA's are liquid and well functioning at time t_o, the cash flow sequence in (2.5) is perceived by the markets as the *correct* sequence to exchange against the floating payments (2.4). But, when we go to the swap cash flows, we see that exactly the same floating cash flow sequence (2.4) is being exchanged for the *known* and fixed swap leg cash flows,

$$\{N\, \delta\, s_{t_o}, \cdots, N\, \delta\, s_{t_o}\} \qquad (2.6)$$

and at exactly the *same* time periods. During both of these exchanges neither counterparty makes any cash payments at time t_o. This means that we can put these two exchanges together at time t_o and get the following conclusion:

- The market is willing to exchange the fixed and *known* cash flows (2.6) against the variable but again *known* cash flows (2.5) with *no* additional time t_o compensation.

This has an important implication, which means that the current values of these two known (fixed) cash flows should be the same. Otherwise one counterparty would demand an initial cash payment. Given that these two sequences of cash flows are known as of time t_o, this equivalence provides an equation that can be used in pricing as discussed next.

2.2.2 Pricing the swap

We have determined two *known* cash flows the market is willing to exchange at no additional cost. Using this we can now calculate the time t_o values of the two cash flows. In order to do this we use the third component of the framework, namely the discount bond prices. For a moment suppose the pure discount bonds $B(t_o, T_i)$, $i = 1, \dots, n$ are liquid, actively traded, and are "correctly" priced. This enables us to use $\{B(t_o, T_2), \cdots, B(t_o, T_n)\}$ to value cash flows settled at times $t_2, \dots, t_n$.[7] In fact, the time-t_o value of the sequence of cash flows in (2.5) will be given by multiplying each cash flow by the *discount factor* that corresponds to that particular settlement date. Bond prices play this role. Doing this for the FRA cash flows first, we obtain:[8]

$$[\ B(t_o, t_2)\, F(t_o, t_1) + \cdots + B(t_o, t_n)\ F(t_o, t_{n-1})\ ]\ N\ \delta \tag{2.7}$$

[7] The fact that we are using default free discount bonds to value a private party cash flow indicates that we are assuming away all counterparty or credit risk.

[8] Here we use the t_i notation for the bond maturity T_i.

The time t_o value of the fixed swap cash flows can be obtained similarly:

$$[\, B(t_o, t_2) + \cdots + B(t_o, t_n) \,]\ s_{to}\, N\, \delta \tag{2.8}$$

Now, according to the argument in the previous section, the values in (2.7) and (2.8) should be the same if all markets are liquid. This equality has, at least, two important implications. First, it again implies that the value of the swap at time t_o will be zero. Second, it can be used as an equation in order to determine the value of *one* unknown, s_{to}. In fact, taking s_{to} as the unknown, we can obtain:

$$s_{to} = \frac{B(t_0, t_2)}{[B(t_0, t_2) + \ldots + B(t_0, t_n)]} F(t_0, t_1) + \ldots + \frac{B(t_0, t_n)}{[B(t_0, t_2) + \ldots + B(t_0, t_n)]} F(t_0, t_{n-1}) \tag{2.9}$$

This is a compact formula that ties together the three important components of the general fixed income framework. It gives the arbitrage-free value of the swap and has a simple interpretation. According to this expression, we see that the "correct" swap rate is a *weighted average* of the FRA paid-in-arrears rates during the life of the swap:

$$s_{to} = \omega_1 F(t_o, t_1) + \cdots + \omega_{n-1} F(t_o, t_{n-1}) \tag{2.10}$$

where the weights are given by:

$$\omega_i = \frac{B(t_0, t_i)}{[B(t_0, t_2) + \ldots + B(t_0, t_n)]} \tag{2.11}$$

Therefore,

$$s_{to} = \sum_{i=1}^{n-1} \omega_i F(t_0, t_i) \tag{2.12}$$

As a result, we may price swaps off the bond market as well.

2.3 Theoretical Determinants of Swap Spreads

First and foremost, we believe that the determinants of swap spreads can be broadly classified into two categories:

- Short-term shock variables that are sensitive to a rise in risk aversion and volatility in interest rate, equity and other markets.
- Business cycle variables that impact the long-run trends in swap spreads.

As far as short-term shock variables are concerned, one could expect a widening of swap spreads when interest rates go up. Since the demand for government bonds increases with rising interest rates and they offer more attractive yields, this would provide a disincentive for managers to buy riskier spread paper. On the other hand, the business cycle/macroeconomic variables, which have potential long-term impact on swap spreads, are usually related to factors such as money supply in the economy, aggregate volume of debt issuance, budget equilibrium and consumer confidence indicators. These factors tend to influence the demand for interest rate swaps on either the fixed side or the floating side, and some of these effects may be cyclical or lagged, but may be significant nevertheless. The slope of the term structure partially takes into account some of these effects. For instance, in early 2000, due to the large surpluses posted by public finances, the US Treasury bought back bonds issued in the market, leading to an abrupt widening in swap spreads.

The rationale of choosing the slope of the Treasury term structure as a proxy for liquidity lies in the observation that the swap curve has gradually replaced the US Treasury curve as the benchmark in gauging relative values by broker-dealers and institutional investors. This variable is found in earlier work to be relevant in explaining business cycle and interest rate dynamics. In principle, the steepness of the yield curve indicates economic and interest rate expectations. For instance, a steepening curve may indicate expectations of an upcoming economic recovery.

Which variable constitutes a suitable proxy for credit? We find that the credit risk affecting swaps is dependant upon the information from the corporate bond market. Hence, TED spread is picked.[9] It is widely believed to be an indicator of credit risk in the banking sector and may be a good proxy for macro-credit risk in the economy. Since US T-bills are considered risk-free while the rate associated with the Eurodollar futures are thought to reflect the credit ratings of corporate borrowers, increasing TED spread is associated with increasing credit risk and vice versa.

Swap spreads serve as a gauge of systemic market risk rather than company-specific risk. It is recognized that when equity markets are volatile, the demand for government bonds go up, in the near as well as long term, due to risk aversion, which induces managers to prefer government bonds to risky bonds or equities. This should be reflected in the widening of swap spreads, as was experienced during the Russian debt crisis. Hence, it would be of interest to see whether it helps to capture more dynamics of swap spreads.

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[9] It is a short-term financing spread.

2.4 Data and Variables

Our data are daily data collected from Bloomberg and CBOE covering the period from November 18, 1996 to March 28, 2003. The swap spread is computed as the differential between the swap rate and the Treasury rate for comparable maturities. In this study we follow other studies and focus our attention on swap spreads of ten-year maturity, which are liquid and commonly analyzed by market practitioners. Descriptive statistics of the data are summarized in Table 2.1. In Figure 2.1 we plot the swap spread, which has a stable average of 37 basis points prior to August 1998 and becomes fairly volatile after that with the average spiking up to 81 basis points.

The two-year Treasury yields in conjunction with the ten-year Treasury yields effectively produce a slope term. A visible upward trend in the slope of the Treasury can be noted after 2000 due to the Fed easing moves.

Essentially, the TED spread the difference between the Eurodollar rate and the US T-Bill rate. During the sample period under consideration, it averages around 34 basis points and exhibits the same movement pattern as the swap spread. Another variable that may have a significant impact on swap spreads is a proxy for market volatility. We employ the Chicago Board Options Exchange's VIX index, since it measures 30-day implied volatility in S&P 500 options and is a standardized, widely followed volatility index that a lot of people recognize. It is often seen as a gauge of investors' confidence in the equity market. A low reading on the VIX indicates complacency among investors about risk, which could mean that share prices are heading for a fall and vice versa. It is our hope that the inclusion of this variable will help to uncover any residual effect on swap spreads besides credit and liquidity.

Plots for the Treasury slope, TED spread and the VIX index are shown respectively in Figure 2.2, Figure 2.3 and Figure 2.4. On average, swap spreads tend to fluctuate within a narrower range towards the later sample period, during the year of 2002 and the early 2003. Against the backdrop of bankruptcies, accounting fraud among US companies and the stock market slump, increased systemic risk in the banking sector has in turn led to a flight to the safe havens of government bonds. As the yield curve becomes even steeper, the overall widening of the swap spread is limited. Another indirect downside pressure comes from the strong refinancing activity on the US mortgage market and it causes the spread to compress.

2.5 Swap Spread Dynamics

2.5.1 Methodology

This subsection briefly describes the VAR model, within which we conduct our analysis.[10] Suppose that the "true" economic structure can be represented as the unrestricted linear dynamic model:[11]

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[10] Employing the VAR methodology, we are able to assess the relative impact of the potential factors on swap spreads. It carries out multivariate ordinary least squares (OLS) estimation within a system where all the variables included are treated as endogenous. The advantage of this is both the instantaneous and the lagged effect of each factor on the swap spread can be captured. Hence, the VAR approach is preferable to single OLS regressions.

[11] Estimating such a VAR with all variables in levels and with suitably long lag order avoids throwing away information and gives consistent estimators.

$$\begin{pmatrix} y_{1t} \\ \cdot \\ \cdot \\ \cdot \\ y_{nt} \end{pmatrix} = \begin{pmatrix} A_{11}(L) & \cdots & A_{1n}(L) \\ \cdot & \cdots & \cdot \\ \cdot & \cdots & \cdot \\ \cdot & \cdots & \cdot \\ A_{n1}(L) & \cdots & A_{nn}(L) \end{pmatrix} \begin{pmatrix} y_{1t} \\ \cdot \\ \cdot \\ \cdot \\ y_{nt} \end{pmatrix} + \begin{pmatrix} \epsilon_{1t} \\ \cdot \\ \cdot \\ \cdot \\ \epsilon_{nt} \end{pmatrix} \quad (2.18)$$

where, $y_{1t}, \ldots, y_{nt}$ denote n discrete time stochastic processes in the model at time t. The $A_{ij}(L)$ are polynomials in the lag operator L:

$$A_{ij}(L) = \sum_{i=1}^{m} a_{ij} L^{i} \quad (2.19)$$

where $i, j = 1, \ldots, n$ and m denoting the maximum lag length. The ϵ_{it} is the corresponding innovation process with mean zero:

$$E_t^P[\epsilon_{it}] = 0 \quad (2.20)$$

and a non-diagonal variance covariance matrix:

$$\epsilon_t = E_t^P \begin{pmatrix} \epsilon_{1t} \\ \cdot \\ \cdot \\ \cdot \\ \epsilon_{nt} \end{pmatrix}' \begin{pmatrix} \epsilon_{1t} \\ \cdot \\ \cdot \\ \cdot \\ \epsilon_{nt} \end{pmatrix} = \sigma^2 \Omega \quad (2.21)$$

where the vector ϵ_{it} is serially uncorrelated.

In this system, we have four equations and four variables. Each variable is allowed to depend on current and lagged values (up to m lags) of all the variables in the model. The vector y contains four variables: liquidity, credit, market volatility and swap spreads. These variables will be referred to respectively as SLOPE, TED, VIX and SS10 henceforth.

An important issue associated with specifying a VAR model is choosing a reasonable lag length. The number of lags employed in the estimation usually varies according to the sample period. In order to select the optimal lag order, we conduct various diagnostic tests.

First, a sequential likelihood ratio test is carried out. For each step (except the first), the true significance level actually differs from the nominal one due to the probability of a type II error at the previous step. Hence at successively lower levels, progressively higher F statistics are required to reject the restrictions at the same true significance level. At the 5% level, the sequential modified LR statistic indicates that 11 lags (corresponding to 11 days) are the optimal lag length. What it implies is that 44 dependent variables (11 lags each for the 4 variables) need to be used in the VAR model. With such large number of variables in the model, it raises questions about the stability and validity of the estimation results due to over fitting.

At the same time, some other information criteria are computed. All test statistics are presented in Table 2.2. Under the criteria of Final prediction error and the Akaike information, eight lags are selected; while the Schwarz information criterion and the Hannan-Quinn information criterion, on the other hand, indicate one lag. The lag length is set equal to eight, since it also ensures that the errors in each equation of the VAR are approximately white noise.

However, the stability of the VAR over time has an important bearing on the validity of certain results from the tests we are going to perform later. For instance, the impulse response standard errors might not be valid if the VAR is unstable. By checking if the characteristic roots of the autoregressive polynomial lie inside the unit circle, we find that our model meets the stability condition.

2.5.2 Estimation Results

2.5.2a Block Exogeneity Wald Test

To gain some additional insights into the interrelations between the four series, we perform a block exogeneity test. Using the Wald test, we can detect whether the past values of SLOPE, TED and VIX could Granger-cause SS10 and can also test the reverse causality from SS10 to these variables.

Table 2.3 summarizes the test statistics under the null hypothesis that the probability of some variable, say SLOPE, Granger-causing SS10 or vice versa is zero. It appears that SLOPE, TED and SS10 are interdependent — SLOPE and TED would Granger-cause SS10; Likewise, SS10 would also Granger-cause SLOPE and TED. Surprisingly, lagged VIX is noted not to have any predictive power on SS10 because we cannot reject the null at conventional significance levels.

2.5.2b Generalized Impulse Responses

After implementing the VAR, we are now able to conduct innovation accounting on swap spreads. A perturbation in one innovation in the VAR sets up a chain reaction over time in all the variables. Via impulse response functions, we can quantify and trace the time path of the effects of a typical shock on the Treasury curve, credit spreads and market volatility on swap spreads.

The conventional method, such as the widely used Cholesky decomposition of the error covariance matrix to orthogonalize the innovations, is rather arbitrary. It presents a potential pitfall, since the analysis of impulse response functions is subject to the "orthogonal assumption". Different ordering of the variables could dramatically change the results of impulse responses. Efforts have been made by Pesaran and Shin (1998) to overcome the disadvantage related to the sensitivity of the impulse response analysis to the VAR ordering.

The *generalized* impulse response functions are estimated based on VAR regressions and provide more robust results. The impulse responses of swap spreads to all the variables in the 8-lag model are depicted in Figure 2.5 and Figure 2.6. In each case, the shock to one of the equations is equal to one-standard deviation of the equation residual and the generalized impulse responses of all the variables to the shock are traced out for a period of 100 days and for a period of two years. The upper and lower standard error bounds of the impulses are computed using Monte Carlo simulation (1000 replications) and are displayed in the graphs alongside the impulse responses.

Generalized impulse response functions capture most of the dynamics over the initial 100 days or so and show dying-out patterns subsequently. As a measure of liquidity, the shape of the term structure of US Treasuries has a negative effect on swap spreads. Following a positive shock to the slope of the yield curve, swap spreads immediately fall by some 1.7bp and then increases slightly to 2bp in six days. The negative impact is persistent and stays statistically significant for quite a few months. Intuitively, the negative response of swap spreads may be interpreted as follows. An increase in the slope of the yield curve often means (especially in our sample period) a cut in short-term financing costs. Being an average of such *expected* costs in the future, swap spreads naturally tend to narrow. In contrast, Duffie and Singleton find that the small negative effect from liquidity turns positive after about two weeks.

Results for the credit shock are not completely uniform. In the first week, it evokes positive response of swap spreads. After that, the response of swap spreads gradually becomes insignificant and permanently negative. This is likely due to hedging and position unwinding through the swap, rather than the cash, market. Duffie and Singleton use another proxy for credit spreads (namely "CPS", the credit spread between BAA and AAA commercial papers), showing slightly different response patterns of swap spreads. It is shown that swap spreads almost do not respond to credit shocks for a few weeks in the beginning and then the same inverse relationship is recorded to be present between credit spreads and swap spreads.

In terms of sources of uncertainty from the market, increasing volatility causes the short-term swap spreads to widen out while the long-term spreads exhibit a narrowing tendency. It is evident from the figure that the most significant responses of swap spreads happen in the first two weeks and responses are much weaker later with wide confidence intervals.

The most significant response of swap spreads is spotted for innovations on the equation of SS10. A shock on swap spreads generates a contemporaneous, positive impact on swap spreads themselves and the effect peaks in two or three days at 9bp. This significant effect levels off over the next 100 days.

2.5.2c Variance Decomposition

Although impulse response functions allow for visual examination of the impact from each variable on swap spreads, we need to ascertain the relative contributions from these variables to the interpretation of the variation of swap spreads.[12] The breakdown of the variations of swap spreads based on the four-variable (SLOPE, TED, VIX and SS10) VAR is summarized in Table 2.4 with a two-year forecasting horizon used. For comparison, results are presented in a way analogous to that of Duffie and Singleton's.

Although similar patterns in responses of the swap spread to its own shock emerge from this study compared to that by Duffie and Singleton, findings regarding credit and liquidity effects are not completely consistent. Nevertheless, as is immediately notable, SLOPE and SS10 together explain primarily all of the forecast error variance of the swap spreads in the initial 100 days. By contrast, VIX is relatively more important than TED over a period of more than one year.

As the time horizon increases, TED gains importance and its explanatory power exceeds that of VIX. 728 days or about two years ahead, TED accounts for 8% of the variance of SS10. Overall, swap spreads' own shock has a dominant role in explaining the variations, diminishing smoothly from (93%) to (73%) over the entire period. SLOPE or liquidity shocks render a pronounced contribution of 13%, the second largest percentage in the decomposition of swap spreads in two years.

These results imply that credit effects become somewhat clear only in the long run, but comparatively less important than liquidity effects. This is confirmed by the prevailing view among swap traders that the swap spread is mainly an indicator of "market liquidity".

[12] Variance decomposition decomposes variation in an endogenous variable into the component shocks to the endogenous variables in the VAR and gives information about the relative importance of each random innovation to the variables in the VAR.

2.5.2d Forecasting Performance

The results in previous sections are all in sample — can the model predict swap spreads out of sample? The VAR model is fitted to the data from November 18, 1996 to November 16, 2000, including the lagged levels of all four variables. The model is then used to forecast all four variable series multi-step ahead for the period from November 17, 2000 to March 28, 2003 using only data prior to November 17, 2000. Before the end of 2000, the market has experienced several major credit and liquidity events as already noted in the introduction. Having accommodated the available information aforementioned, the model is expected to accomplish a reasonable forecasting task for the ensuing years.

As can be seen in Figures 2.7, 2.8, 2.9 and 2.10, the levels of the forecasts are usually lower than the actual data except for the variable TED, whose forecasts are higher. The major trends in the series appear to be reasonably well reflected. The only drawback of these forecasts is that they fail to capture the substantial swings in SS10, SLOPE and VIX. This is not unexpected, because the presence of right-hand side lagged dependent variables has made the forecasting complicated. In this dynamic forecasting process, the recursively computed forecast of the lagged value of the dependent variables are used in each subsequent period after the first. Therefore, any error made in the initial forecasting will be carried forward in subsequent forecasts. If we narrow the forecasting horizon, in theory the model should yield improved results. In fact, Figure 2.11 shows that the one-year SS10 forecasts track the actual data particularly better compared to the longer-period forecasts achieved earlier.

2.6 Conclusions

The present study has reinvestigated whether factors, such as liquidity and credit, contribute to and help predict the evolution in the spread between the US interest rate swap and the Treasury over the period November 1996 to March 2003. To assess the relative importance of SLOPE, TED, VIX and SS10, a vector autoregression model is used. By comparing our estimation results with those of Duffie and Singleton's, we are able to identify a number of differences and similarities of the swap market before and after the mid 1990s.

Estimation results suggest growing importance over time for all the variables, except SS10. It reveals that liquidity has a persistent negative effect on the change of the swap spread and is highly significant in determining the swap spread's variation. In contrast, Duffie and Singleton find a generally positive liquidity effect, except for a small negative effect in the initial two weeks.

Taking the three-month Treasury Eurodollar spread as a proxy for credit, we find that its overall role as a determinant of swap spreads is smaller than that of liquidity. One key difference from that of Duffie and Singleton's is that the importance of credit fails to show up even in the long run. Following a positive shock to credit, the swap spread would immediately rise, but within ten days it would tighten.

A widening of the market volatility is usually associated with an increase in swap spreads, but such an effect is relatively short-lived, subsiding after the first few months. Despite a detected, counterintuitive zero effect on SS10 in the block exogeneity test, VIX provides weak explanation of the variation of swap spreads.

As noted in the results, the swap spread explains the preponderance of its own forecast error variance. This has likewise been observed in Duffie and Singleton's. However, while 73 percent of the variations of swap spreads in two years are attributable to their own shocks in our model, Duffie and Singleton's result is much smaller, between 35 percent and 48 percent.

It is our belief that this study could serve as another pragmatic interpretation of swap spreads in the literature. The empirical findings presented here prove that the most recent US market experience evidences a strong relationship between *liquidity* and swap spreads. We argue that credit risk is much less important today in the swap market than in the 1980's and swap spreads may be viewed to be mainly driven by liquidity risk in the market. For this reason, the next phase of the US economy and the resultant response of the Fed will exert a powerful bearing on the dynamics of swap spreads over time.

2.7 References

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Table 2.1 Summary Statistics of Data

	VIX	TED	SS10	SLOPE
Mean	26.79	0.34	0.69	0.66
Standard Deviation	6.08	0.28	0.38	0.83
Skewness	1.21	0.57	0.26	0.77
Kurtosis	4.28	4.46	3.06	2.16

Table 2.2 Lag Length Selections

Lag	LR	FPE	AIC	SIC	HQIC
1	21762.66	1.05E-07	-4.72	-4.65*	-4.70*
2	58.82	1.03E-07	-4.74	-4.62	-4.69
3	21.57	1.03E-07	-4.73	-4.55	-4.67
4	38.06	1.03E-07	-4.74	-4.50	-4.65
5	52.18	1.02E-07	-4.75	-4.46	-4.64
6	38.07	1.01E-07	-4.75	-4.41	-4.63
7	36.45	1.01E-07	-4.76	-4.36	-4.61
8	36.74	1.01E-07*	-4.76*	-4.31	-4.59
9	27.28	1.01E-07	-4.76	-4.25	-4.57
10	11.34	1.02E-07	-4.75	-4.18	-4.54
11	28.30*	1.02E-07	-4.74	-4.13	-4.51
12	17.82	1.03E-07	-4.73	-4.06	-4.48
13	26.19	1.04E-07	-4.73	-4.00	-4.46
14	25.06	1.04E-07	-4.73	-3.95	-4.44
15	21.12	1.04E-07	-4.72	-3.88	-4.41

Notes:
An asterisk indicates the lag order selected by the criterion. Except for LR test, the lowest number is chosen for the other criteria.
LR: Sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SIC: Schwarz information criterion
HQIC: Hannan-Quinn information criterion

Table 2.3 Block Exogeneity Wald Test

	Chi-square	P-value
SLOPE→SS10	19.09	0.01
SLOPE←SS10	18.55	0.02
TED→SS10	36.57	0.00
TED← SS10	18.85	0.02
VIX→SS10	6.35	0.61
VIX←SS10	5.40	0.71

Note: The null hypothesis is that the probability of X Granger-causing Y is zero.

Table 2.4 Variance Decomposition of Swap Spreads

Horizon (days ahead)	SLOPE	TED	VIX	SS10
7	4.18	2.07	1.72	92.03
	(2.22)	(1.88)	(1.51)	(38.67)
28	5.68	1.06	2.91	90.35
	(1.83)	(1.08)	(1.12)	(23.05)
56	7.17	1.02	3.25	88.57
	(1.80)	(0.53)	(0.81)	(15.59)
182	9.56	1.60	3.38	85.46
	(1.85)	(0.58)	(0.71)	(11.43)
364	10.91	3.83	4.12	81.14
	(1.83)	(0.83)	(0.79)	(7.85)
546	12.16	6.03	4.82	76.99
	(1.72)	(0.87)	(0.81)	(5.63)
728	13.35	8.13	5.49	73.03
	(1.59)	(0.89)	(0.82)	(4.33)

Duffie and Singleton's results

Horizon (weeks ahead)	TB6	REPOSP	CPS	ZEROSP10
1	2.44	0.69	0.12	96.75
4	6.29	2.74	0.13	90.85
8	12.00	11.90	0.16	75.95
26	15.26	12.88	6.98	64.88
52	12.84	18.60	16.75	51.81
78	11.55	19.88	19.46	49.11
104	11.22	20.13	20.29	48.46

Notes:

(1) Numbers in parentheses are t statistics.

(2) The columns give the percentage of the variance due to each innovation; each row adds up to 100.

(3) TB6: 6-month Treasury bill rate; REPOSP: spread between generic and on-the-run repo rates for ten-year Treasury bonds; CPS: spread between BAA- and AAA-rated commercial paper; ZEROSP10: spread between ten-year zero rates implied by the swap and Treasury markets.

Figure 2.1: Ten-year Swap Spreads

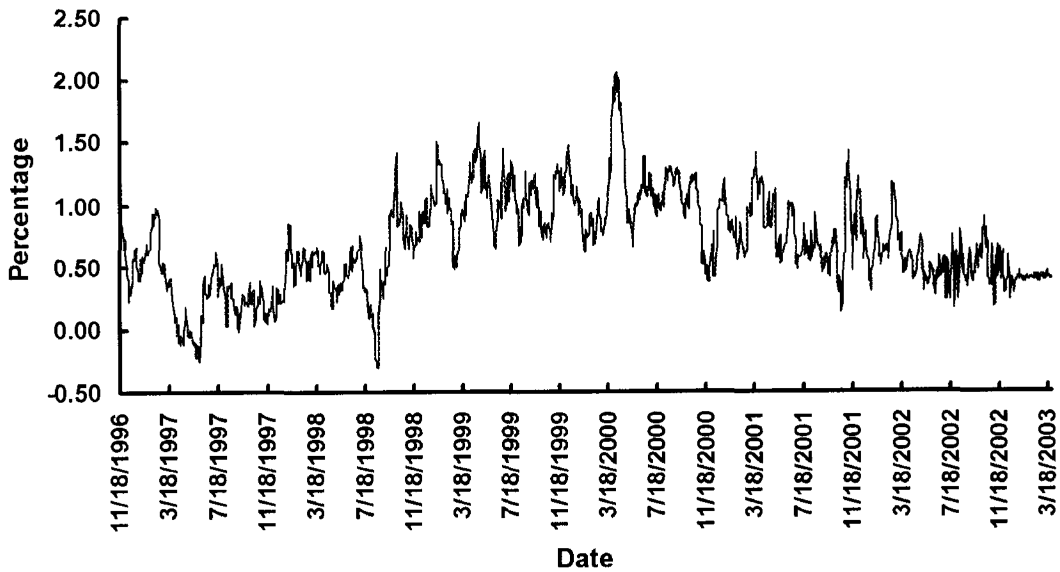


Figure 2.2: Slope of the Treasury

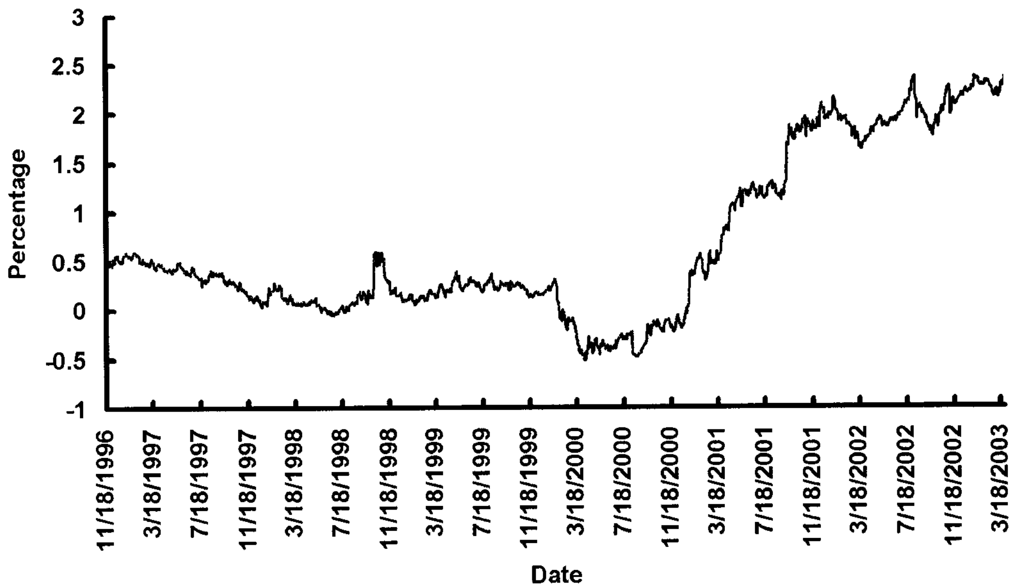


Figure 2.3: Three-month TED Spreads

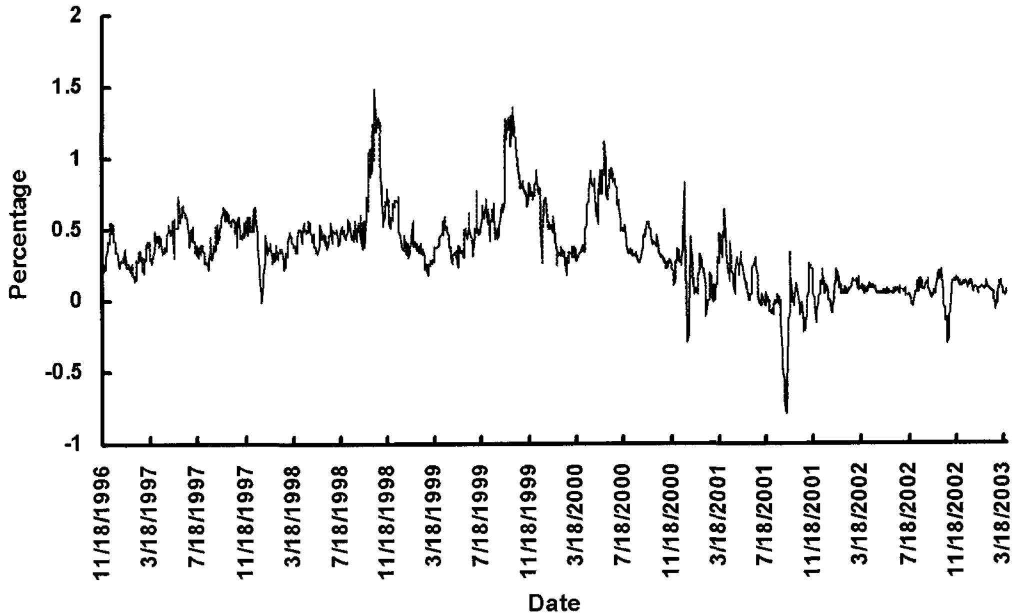


Figure 2.4: VIX Index

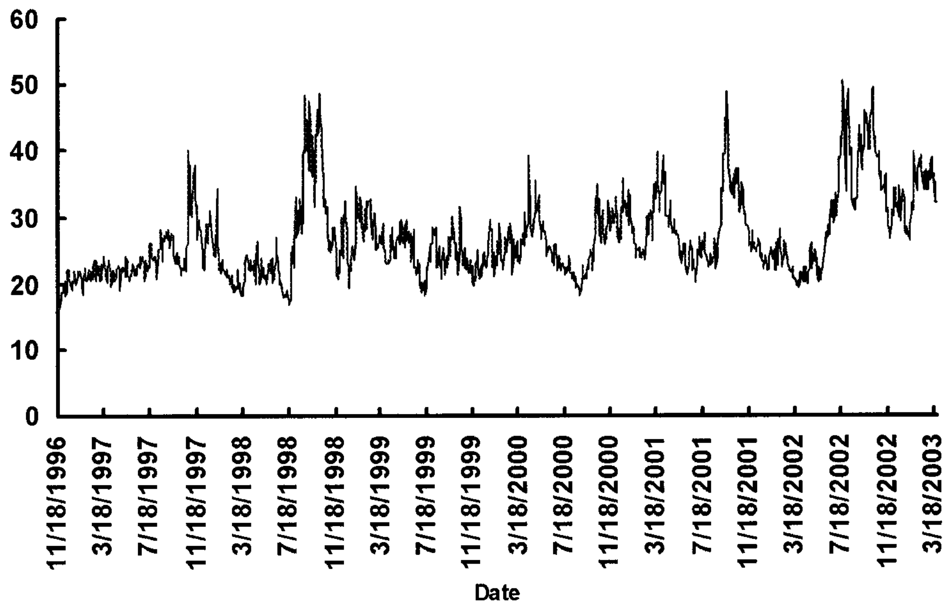
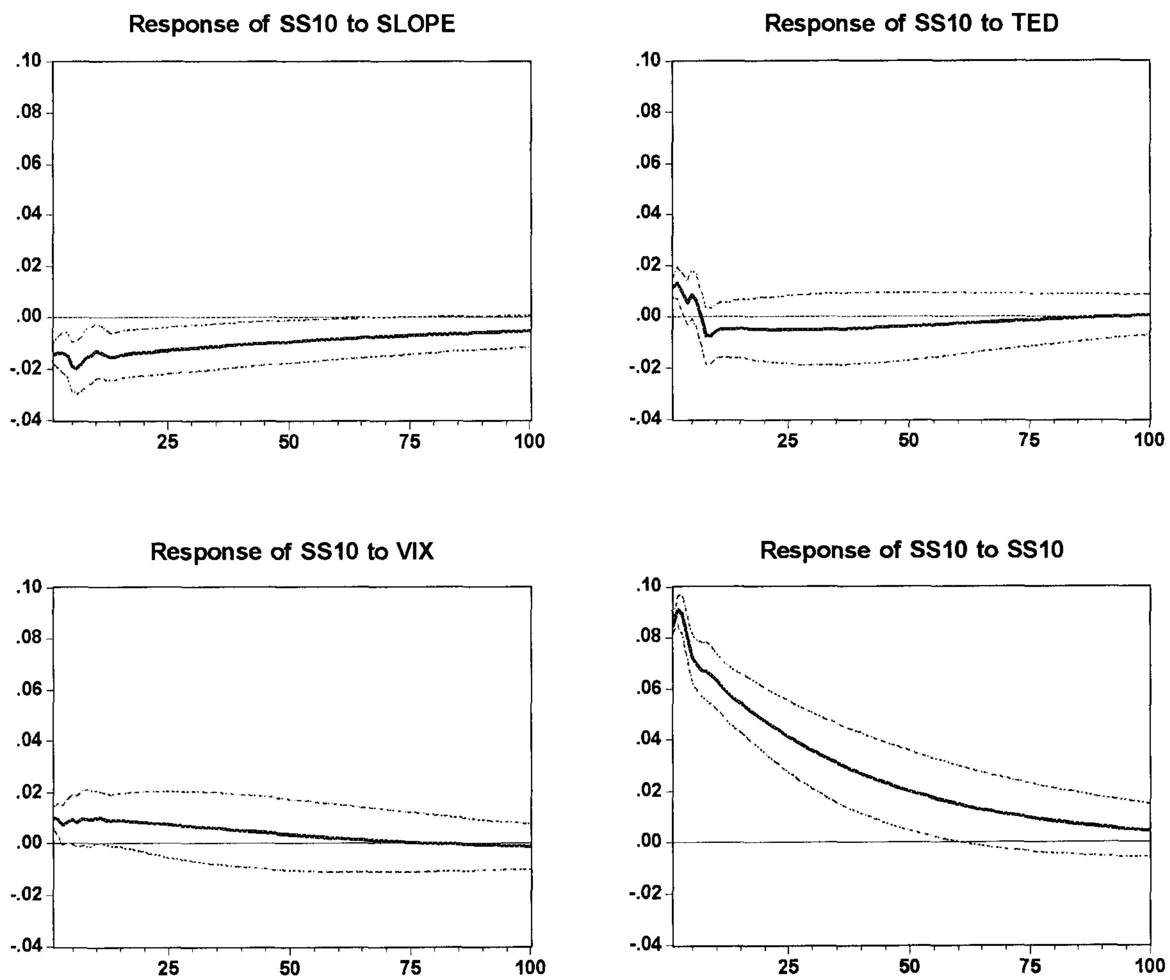
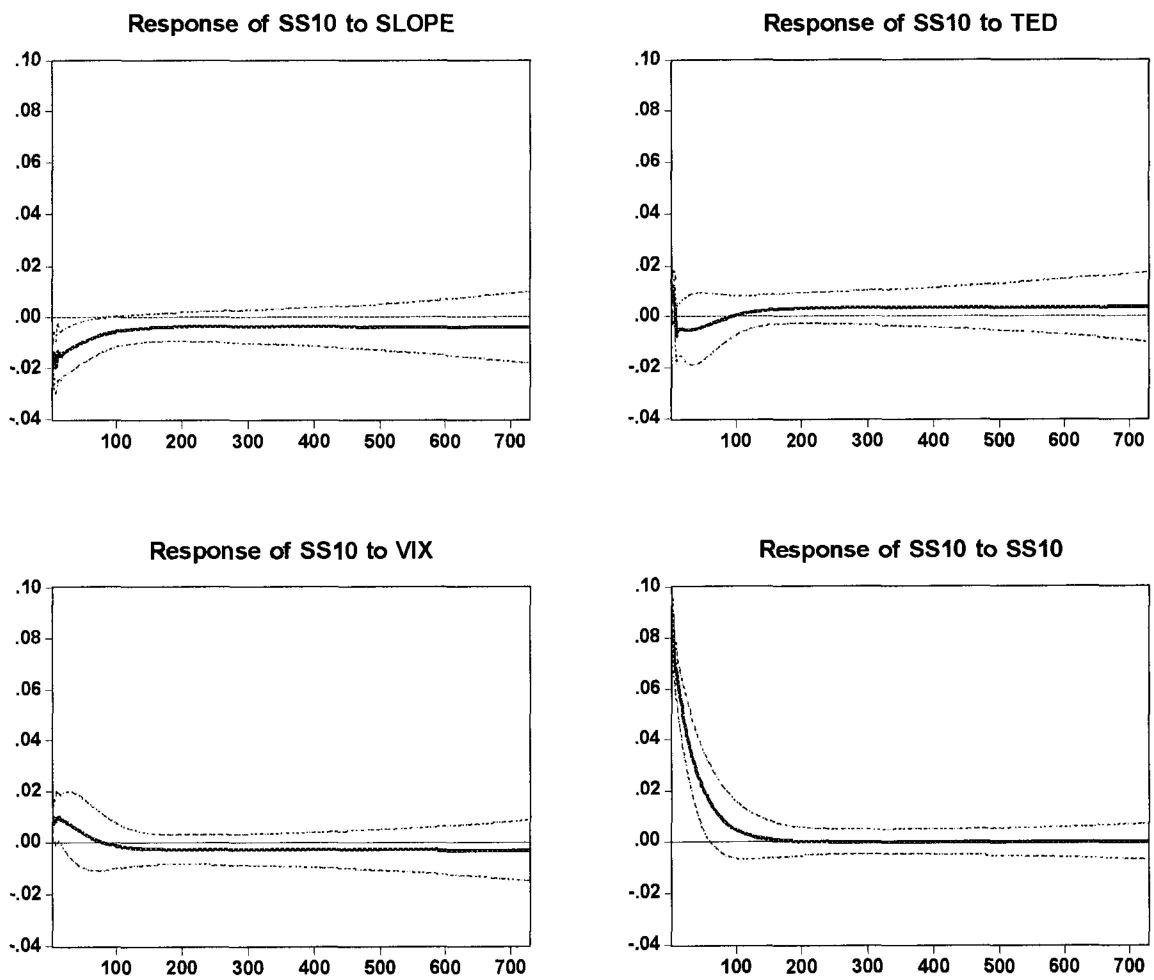


Figure 2.5: Generalized Impulse Responses (100 days)



Note: The generalized impulse response functions show the responses of swap spreads to one-standard deviation innovations imposed on the variables with plus and minus two-standard error bands during the initial 100 days.

Figure 2.6: Generalized Impulse Responses (two years)



Note: The generalized impulse response functions show the responses of swap spreads to one-standard deviation innovations imposed on the variables with plus and minus two-standard error bands in a period of two years.

Figure 2.7: Dynamic Forecast of SS10

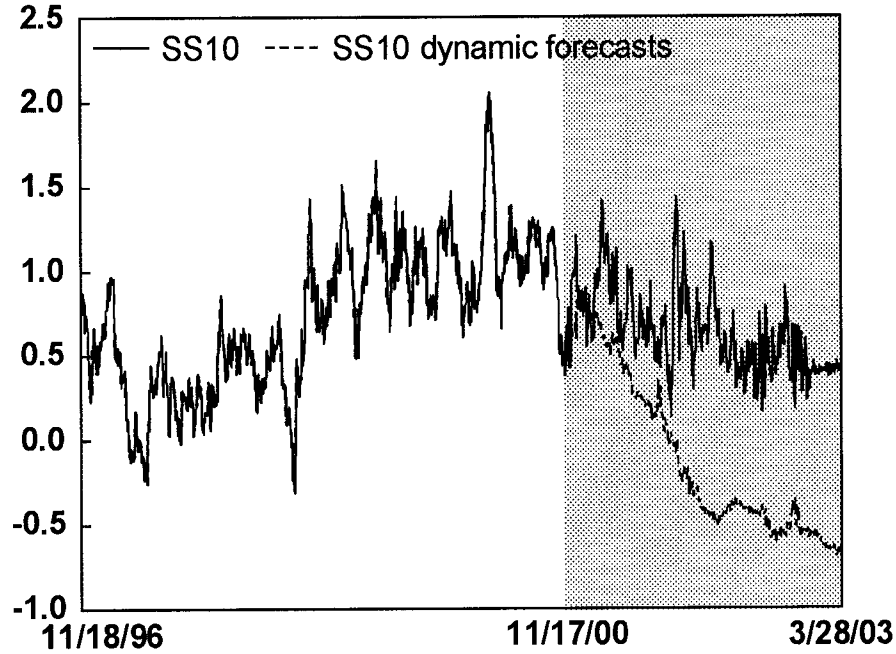


Figure 2.8: Dynamic Forecast of SLOPE

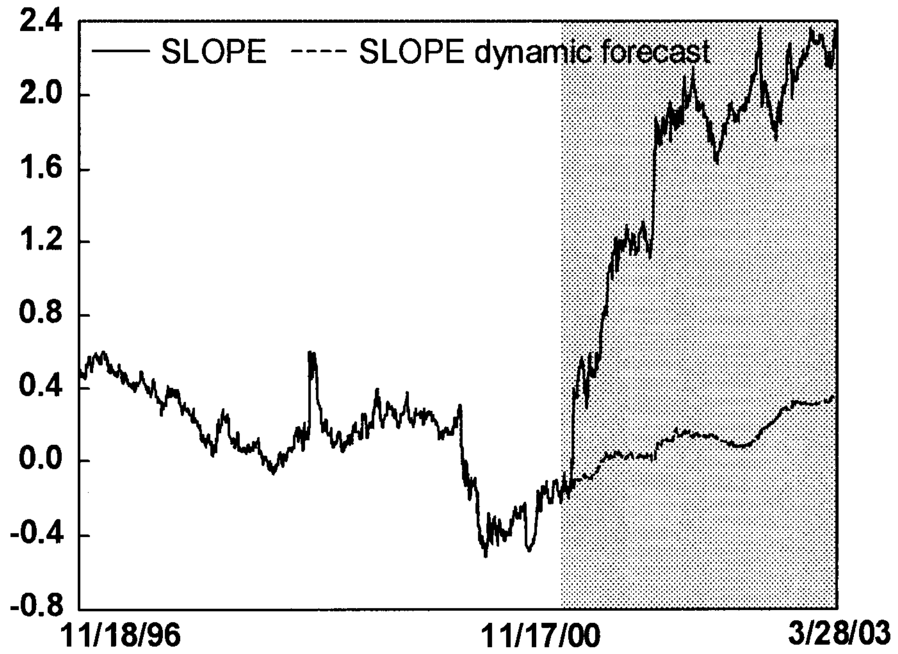


Figure 2.9: Dynamic Forecast of TED

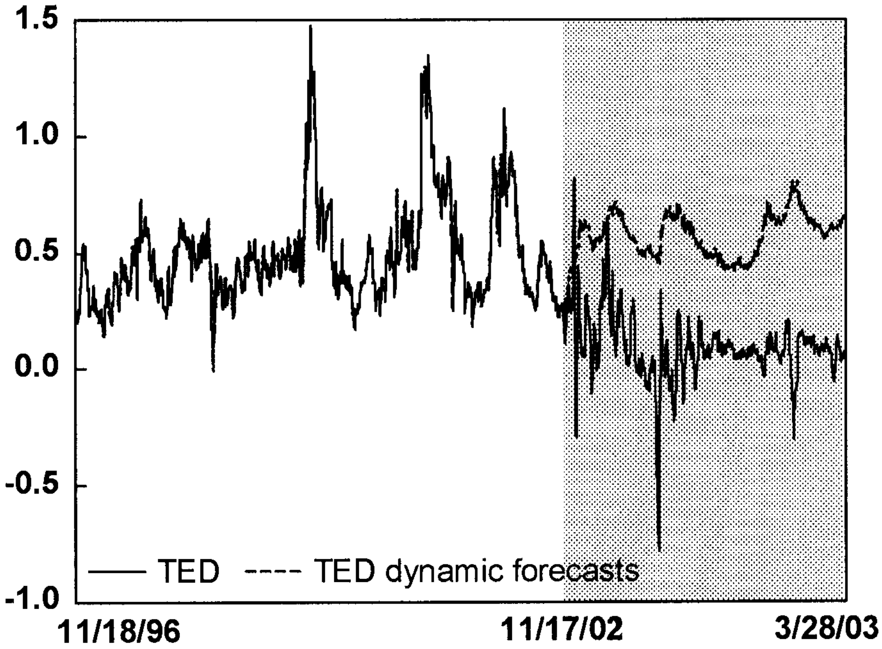


Figure 2.10: Dynamic Forecast of VIX

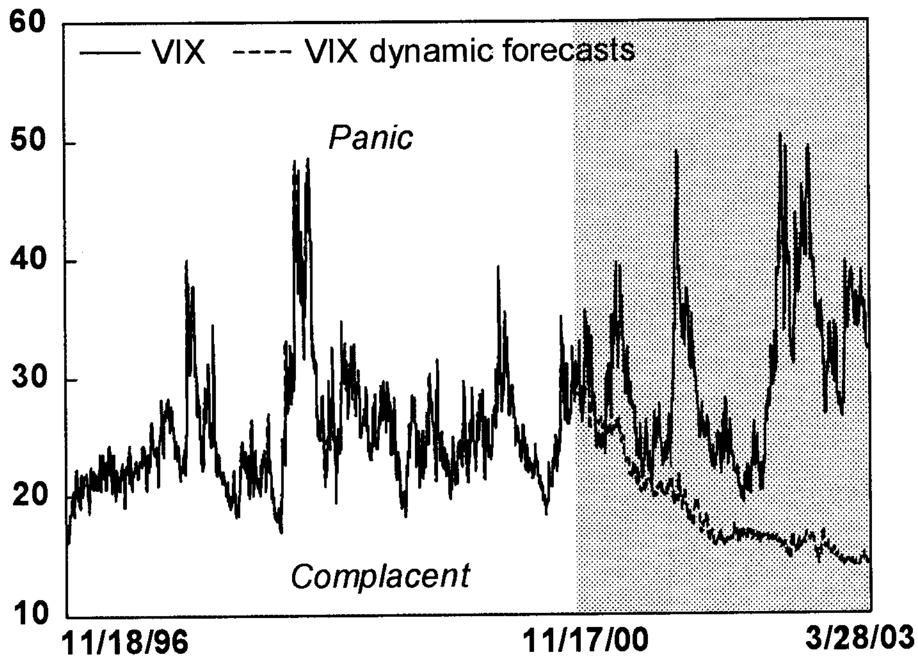
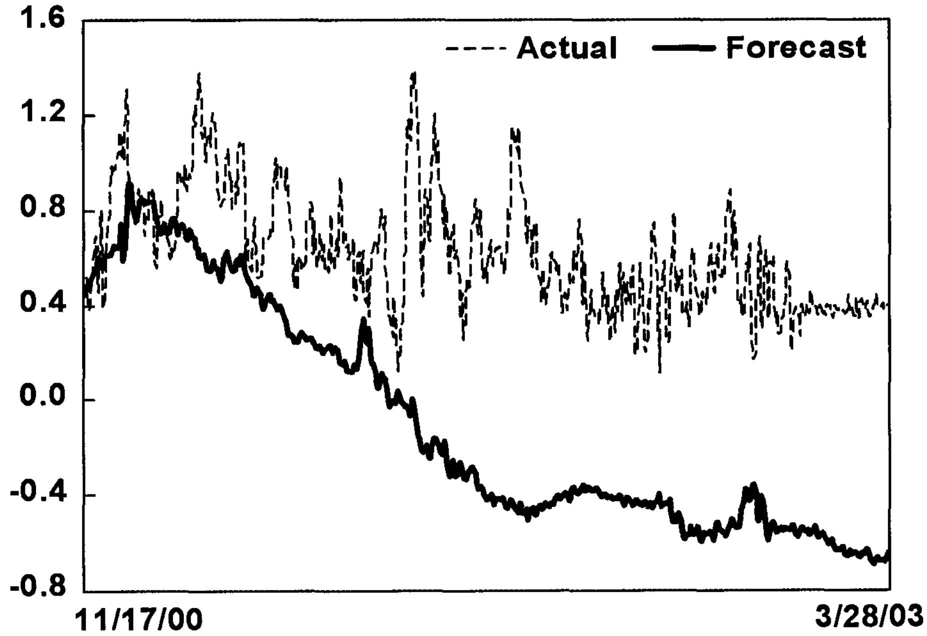
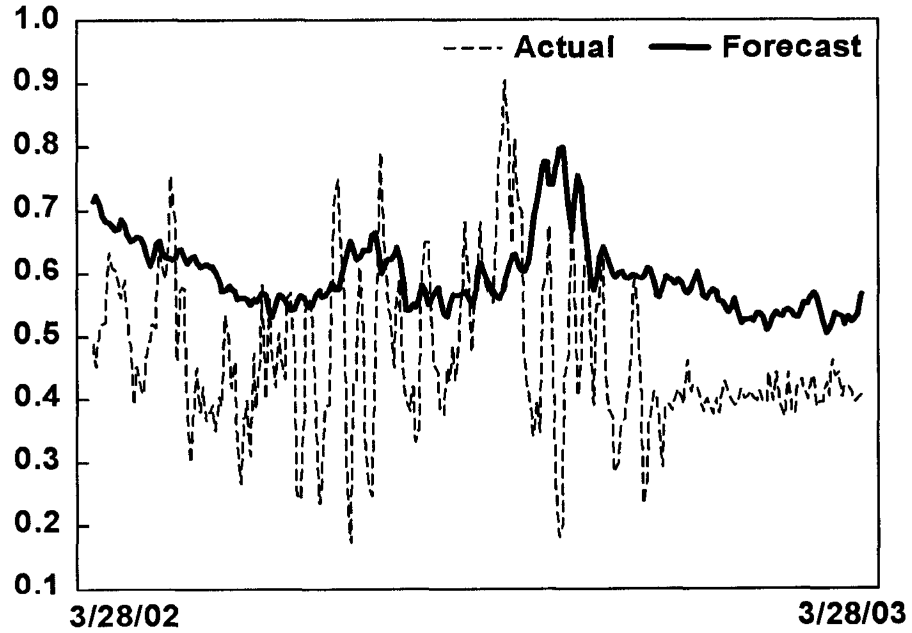


Figure 2.11: Forecasts Comparison





Note: The shorter the forecasting horizon, the better the forecasts.

Chapter 3

A Note on a Cointegrating Vector for US Interest Rate Swaps

3.1 Introduction

It has been recognized that swap spreads[13] are generally influenced by the interplay of several complex factors. Within a vector autoregressive model (VAR) framework, we conduct empirical cointegration analysis on US interest rate swap spreads, the London Interbank Offered Rates (LIBOR), corporate credit spreads and the shape of the Treasury yield curve. If cointegration exists, it implies a stable long-run relationship among them, and the variables cannot wander far away from each other arbitrarily over time. In this note the dynamics of interest rate swap spreads is shown to depend on a cointegrating vector obtained from fixed income and credit markets. We show that this vector is highly correlated with US equity indices, indicating complex dynamics between the swap and the equity markets that has not been documented before.

In order to examine the cointegrating relationship among the variables, this study performs the Johansen (1988) cointegration tests. The presence of one cointegrating relationship indicates that there is an error correction representation of the model, which is deemed as an effective way of characterizing the dynamic multivariate interactions when cointegrating relationships are present. Therefore we further apply the theory of error correction. Results suggest that the selected variables are well modelled as a cointegrated system.

The note is organized as follows. The second section gives an overview of the existing literature on the determinants of swap spreads and provides theoretical considerations for the choice of variables in our study. In section 3.3 we describe

[13] The differential between interest rate swaps and their Treasury counterparts with the same maturity.

the data and present the econometric models of cointegration and error correction. Section 3.4 contains the interpretations of the estimation results and of the obtained cointegrating vector. The final section concludes.

3.2 Determinants of swap spreads

Recent studies show mixed interactions between swap spreads, credit risk and liquidity factor. Duffie and Singleton (1997) develop a term structure model for swap yields, which are regarded as par bond rates of a LIBOR-quality issuer. They find very different responses of swap spreads to liquidity shocks and to credit shocks, with significant impact from liquidity effect in the short run while credit effect being a major determinant only over longer horizons. Other papers, such as He (2001) and Solnik (2001), argue that swap contracts are essentially risk-free due to the extensive use of collateral nowadays. Variation in swap spreads is ascribed to the change in liquidity risk by Grinblatt (2001). Minton (1997) also finds weak evidence that swap rates are sensitive to the credit spread between AAA and BAA rated bond yields. At the same time, in this strand of literature, results reporting credit risk in the interest rate swap market can be found in Cossin and Pirotte (1997) and Liu, Longstaff, and Mandell (2002).

Our basic motivation is to investigate empirically whether a *stable* long-run relationship exists between the US interest rate swap spreads and a few likely underlying variables (among inexhaustible many) that tend to impact the dynamics of swap spreads. Hence, the incorporation of the following variables: the 10-year US interest rate swap spreads (SS_{10}), 6-month LIBOR rates (LIBOR), the shape of the Treasury yield curve (SLOPE), corporate credit spreads (CREDIT) and the modified duration of the corporate bonds in the relevant credit category (DURATION).

Now, it is worth emphasizing the dual nature of the credit risk involved: On the one hand, interest rate swaps are assumed to be close to risk-free — the general swap rate is only for highly rated counterparties, and there is no principal to default on. Counterparties lose money only if they are a net receiver when the other party defaults. In addition, many swap agreements require collateral. On the other hand, the floating rate used most often in the swap market to reference a swap rate to is the LIBOR rate and this means that swaps can be thought of as derivatives on LIBOR rates. Although LIBOR is a standardized rate, set by the British Banker's Association, it is an *unsecured* rate, at which major international banks can borrow funds from each other without posting collateral. Therefore, having little credit risk of their own, swaps do reflect a certain credit risk.

The reason to consider 6-month LIBOR is twofold: first, it is commonly used for the floating leg of the US dollar interest rate swaps; second, it is widely viewed as an "effective proxy for banking liquidity". Swap rates can be derived as the weighted average of the expected future LIBOR rates, i.e. the LIBOR forward rates over the life of the contract. At the time a swap contract is entered into, the contract is valued at its fair value if it is attributed a value of zero at the beginning. This occurs only if the present value of future net payments equals zero. Usually the implied forward rates change daily with the movements of the yield curve. It means that in the course of time the swap will acquire a positive or a negative value, which corresponds to the present value of the future flow of payments.

Since the yield curve of the US Treasury is taken as reflecting the market expectation on future interest rates, there should be a relationship between the shape of the yield curve and the swap spreads. In an environment of steep yield curve, issuers of fixed-rate debt have higher incentives to reduce their interest burden by swapping into synthetic floating-rate debt. This creates a supply surplus (more floating-rate payers) on the swap market, resulting in lower swap rates and narrower swap spreads. Vice versa, in the case of an inverted yield curve, rising swap rates and wider swap spreads are expected.

The two-year and the ten-year on-the-run (OTR) Treasury yields can be used to produce the Treasury yield curve slope. As displayed in Figure 1, swap spreads almost always move in the opposite direction of the slope of the yield curve. For instance, in the first half of the year 2000, swap spreads widened as Treasury yields lowered due to the continuing shrinkage in the supply of long-term notes. By contrast, the later Fed easing moves caused the Treasury curve to steepen and led to narrowing swap spreads.

Finally, note that banks are the most important market participants in the swap market. The credit risk of the banking system depends strongly on the creditworthiness of the corporate sector. Whenever credit spreads increase, credit risk of the banking system also rises and so does the risk premium priced into the swap rates. As Evans and Bales (1991) point out, swap spreads have generally been lingering within the range defined by AA- and A-rated new-issue spreads in the domestic and international bond market, and longer-dated interest rate swaps are influenced significantly by the corporate bond market. Accordingly, corporate credit spreads are indispensable in our analysis. We investigate in the following sections whether there exists a cointegrating vector between the variables mentioned above and what feature it possesses.

3.3 Cointegration analysis

Cointegration procedures help to retain all the information about potential equilibrium relationship between nondeterministic time series without any initial data transformations. In this section we are interested in obtaining a constant parameter vector β, a cointegrating vector, if there is any, by adopting the Johansen's maximum likelihood (ML) method.

3.3.1 Data

The data used in this study are primarily Liquid US Corporate Index (LUCI) data from Credit Suisse First Boston.[14] LUCI is a market capitalization weighted index of over 500 High Grade US Corporate bonds. The index is separated into categories based on ratings by Moody's Investor Service and Standard & Poor's. All data within the various rating categories are the weighted average of all bonds within the grouping. There is no "missing" data within the LUCI index because all trading days are included and end of day prices are given by traders. Only closures of the market cause any gaps in the data series.

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The estimations utilize daily data from January 4, 1999 to March 8, 2002,[15] including 10-year USD swap spreads, LUCI-A benchmark spreads, LUCI-A modified duration,[16] OTR Treasuries for both two-year and ten-year maturities, and 6-month LIBOR. Credit components are proxied by LUCI-A benchmark spreads, which are the weighed average credit spreads of the A-rated US corporate bonds. Note that the LUCI-A rating categories are near the ten-year average weighted maturity, we also allow the modified duration of LUCI-A category into the analysis. The inclusion of the LUCI data enables us to obtain finer results,[17] since such daily data were not available until the last few years. Figures 3.1 to 3.5 plot 10-year USD swap spreads, the slope of the Treasury yield curve, 6-month LIBOR, LUCI-A credit spreads and LUCI-A modified duration.

3.3.2 Methodology

Empirically the variables in a vector autoregression (VAR) model should be stationary or transformed into stationary variables for the asymptotic theory to be valid. A VAR in first-differences would be appropriate when the variables are integrated of order one (while not cointegrated). However, if they are *cointegrated* then the lagged equilibrium error(s) should be included as regressor(s) into a dynamic specification of an error correction model (ECM).[18]

As pretests, we conduct unit root tests to assess the order of integration of each variable sequence. Augmented Dickey-Fuller test shows that they are all non-

[15] Before August 1998, US swap spreads had been traded within a stable range.
[16] Modified durations have already taken convexity into account.
[17] Weekly data are commonly used in other papers.
[18] Engle and Granger (1987).

stationary I(1) variables, as most financial time series are. The choice of lag length is a crucial step in the construction of a VAR model to be evaluated. We use several information criteria to choose the lag structure of the model. In Table 1, three lags (in terms of levels of the variables) over other orders are suggested unambiguously by the sequential modified likelihood ratio test statistic (LR), Akaike's final prediction error (mean square prediction error, or FPE) criterion and Akaike information criterion (AIC). Opting for three lags, we proceed to implement Johansen's (1988) multivariate cointegration test as follows.

To proceed, we consider a standard VAR:

$$Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + A_3 Y_{t-3} + \varepsilon_t \qquad (3.1)$$

where Y stands for a (5 × 1) vector of SS (10-year swap spreads), SLOPE (slope of the Treasury yield curve), CREDIT (LUCI-A credit spreads), LIBOR (6-month LIBOR), and DURATION (LUCI-A modified duration) respectively, and ε_t is a vector of white noises with mean zero and finite variance. This VAR can be rewritten as:

$$\Delta Y_t = \Gamma_1 \Delta Y_{t-1} + \Gamma_2 \Delta Y_{t-2} + \Pi Y_{t-1} + \varepsilon_t \qquad (3.2)$$

where Δ is the first difference operator, coefficient matrix $\Pi = A_1 + A_2 + A_3 - I$, and coefficient matrix

$$\Gamma_i = -\sum_{j=i+1}^{3} A_j \quad , \; i = 1, 2 \qquad (3.3)$$

The number of distinct cointegrating vectors can be obtained by checking the rank of Π or the significance of the eigenvalues of Π. Johansen's method is to estimate the Π matrix from Equation (3.2) and use likelihood ratio test to test for the hypothesis that there are at most *r* cointegrating vectors.[19]

Two restricted maximum likelihood ratio test statistics are employed: the Trace test statistic and the Maximal Eigenvalue test statistic (Johansen and Juselius, 1990). The trace statistics test the null hypothesis that the number of distinct cointegrating vectors is less than or equal to *r* (the number of cointegrating relationships) against a general alternative.[20] While in the maximal eigenvalue test, the null hypothesis is that there is no cointegrating relationship among the variables and the alternative hypothesis is that one cointegrating vector exists.

3.3.3 Estimation of the long-run cointegrating relation

Table 3.2 contains the cointegration rank test of the data. Overall, the results of both the trace and maximal eigenvalue tests indicate one cointegrating vector ($r = 1$) at both 5% and 1% levels. The existence of one cointegrating vector asserts that there is one linear combination between swaps spreads and the other four variables for which the variance is bounded. By Granger's representation theorem (Engle and Granger, 1987), Π in Equation (3.2) can be represented by $\Pi = \alpha\beta'$, with both α and β (5×1) being column vectors. The elements in α are known as the adjustment parameters. $\beta = (\beta_1, \beta_2, \beta_3, \beta_4, \beta_5)'$ is the cointegrating vector, such that $\beta' Y_t$ is stationary or integrated of order zero.

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[19] It is most commonly used. In-depth discussions of the methodology and procedure can be found in many texts.

[20] For instance, you can test the null hypothesis $r \leq 0$ against the alternative $r = 1, 2, 3$ or 4.

The Johansen MLE of the cointegrating coefficients are presented in Table 3.3. When the system is in long-run equilibrium, we have $\beta' Y_t = 0$. Then we are able to obtain the following equation for swap spreads after normalizing the cointegrating coefficient on swap spreads:[21]

$$SS_{10} = -1.008 - 0.059 \times SLOPE + 0.969 \times CREDIT + 0.012 \times LIBOR + 0.098 \times DURATION \quad (3.4)$$

3.4 Interpretation in an error correction model

Engle and Granger establish that an error correction representation can always be written for a cointegrated system. In this section we illustrate how the above cointegration result may be utilized within an ECM framework.[22] According to Engle and Granger (1987), an error correction representation that incorporates levels and differences of variables can be adopted for a cointegrated system. To this end, denoting the cointegration error as e,[23] we write the ECM-VAR representation as:

$$\Delta Y_t = \sum_{j=1}^{n} \alpha_j e_{j,t-1} + \sum_{i=1}^{m} A_i \Delta Y_{t-i} + \epsilon_t \quad (3.5)$$

Here A is an m × m coefficient matrix, which consists of the short-run parameters — the coefficients on the lagged first-difference terms. The number of cointegrating vectors and the number of lags in lagged first-difference terms are designated by n and m respectively, with $n = 1$ and $m = 2$ as determined in the

[21] As the cointegrating vector is not unique, normalization is necessary.
[22] Due to the error correction mechanism, the ECM is proved to be superior to VAR in forecasting economic courses when the included time series are cointegrated.
[23] It measures the extent to which the system of the variables is out of equilibrium. It is also called the "equilibrium error".

previous section. The residual from the cointegrating regression, e_{t-1}, is built into the specification and labelled as the *error correction* term. It is a measure of the error or deviation from equilibrium. Each element of α is one feedback coefficient and measures the speed of adjustment of each variable towards the equilibrium. As a result, the long-run behavior of the variables is restricted to converge to their long-run equilibrium while short-run adjustments are also allowed. Results from the ECM estimation for swap spreads are reported in Table 4. If written out, the equation is:

$$\Delta SS_{10,t} = 0.0003 \times e_{t-1} + 0.20 \times \Delta SS_{10,t-1} - 0.16 \times \Delta SS_{10,t-2} - 0.02 \times \Delta SLOPE_{t-1} - 0.02 \times \Delta SLOPE_{t-2} + 0.08 \times \Delta CREDIT_{t-1} + 0.003 \times \Delta CREDIT_{t-2} + 0.04 \times \Delta LIBOR_{t-1} + 0.02 \times \Delta LIBOR_{t-2} - 0.01 \times \Delta DURATION_{t-1} - 0.002 \times DURATION_{t-2} + \varepsilon_{1,t} \quad (3.6)$$

In particular, the cointegration error based on the cointegrating vector is given by:

$$e_{t-1} = 1.008 + SS_{10,t-1} + 0.059 \times SLOPE_{t-1} - 0.969 \times CREDIT_{t-1} - 0.012 \times LIBOR_{t-1} - 0.098 \times DURATION_{t-1} \quad (3.7)$$

The results of the error correction model reveal not only the implied long-term trend, but also the short-run shocks in modelling swap spreads. The cointegrating regression indicates that swap spreads are positively correlated with all the variables, except for the slope of the Treasury yield curve. Corporate credit spread is statistically significant and adjusts almost one for one with the swap spread in the long run, given ceteris paribus conditions. It implies that credit spread emerges as the main economic determinant in the behavior of swap spreads over the long run. This long-run equilibrium relationship prevents any of the variables from deviating too far out of the line over time and it describes the tendency of this system to move toward a particular point over time.

Although the error correction term enters as an explanatory variable in the ECM, the term does not play a statistically significant role in determining the dynamic path of swap spreads. In terms of short-term shocks, the first lag of the first-difference terms of swap spreads, credit and LIBOR display positive and strong statistical influence on swap spreads. The slope of the Treasury yield curve only has a marginally significant, negative short-run effect on swap spreads. Additionally, DURATION lends little explanatory power to swap spreads, as the regression results indicate that it shows no statistical significance.

More explicitly, we compare this cointegrating vector with the time series of Nasdaq composite index. Figure 3.6 shows that the cointegrating vector exhibits strikingly similar movement patterns to those of Nasdaq composite index during the sample period. For instance, it can be seen that as the Nasdaq stock market fell to its lowest level in years in the wake of September 11, the cointegrating vector also made huge plunge around the same time. It appears that there is a strong *positive* correlation (*0.57*) between the two time series. We deduce that this result renders empirical evidence that complex dynamics exists between the swap and equity markets in the US.

3.5 Conclusions

Given the extensive use of swaps in pricing, balance sheet management, hedging and trading, understanding swap spreads should therefore deserve more attention. We have explored the dynamics of interest rate swap spreads within a cointegrated system.

We find that swap spreads, LUCI-A credit spreads, the shape of the Treasury yield curve, and 6-month LIBOR pass the statistical tests for cointegration and are cointegrated of order one. An error correction model, implied by this cointegrating relationship, is therefore estimated. Interpreted as an effective way of characterizing the dynamic multivariate interactions among economic data, ECM demonstrates that swap spreads react to both the long-run corrective restoring force and the short-run fluctuations in all the variables.

In particular, the finding suggests that the short-run change in the slope of the Treasury yield curve has a marginally significant, negative effect on swap spreads; while the short-run changes in corporate credit spreads, 6-month LIBOR, and swap spread itself all exert positive, significant impact on the movement of swap spreads. This is consistent with what we expect at the outset.

Furthermore, with the error correction term derived from the cointegrating regression, we believe that the presence of a special long-run relationship reflects the common responses of the variables to changes in economic fundamental factors. Additional work can be done by making use of the knowledge of e_t on how to improve the forecast of one or all the variables.

Most importantly, the cointegrating vector obtained from the fixed-income and credit markets exhibits a high degree of correlation with the Nasdaq composite index, suggesting the understanding of the USD swap market should be extended to the equity market as well.

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Table 3.1 VAR Lag Order Selections

Lag	LogL	LR	FPE	AIC
0	-504.98	NA	2.54E-06	1.31
1	8223.36	17322.56	5.31E-16	-20.98
2	8349.73	249.18	4.10E-16	-21.24
3	8386.68	72.38*	3.98E-16*	-21.27*
4	8403.06	31.88	4.06E-16	-21.25
5	8419.71	32.19	4.15E-16	-21.23
6	8435.59	30.50	4.25E-16	-21.21
7	8446.56	20.93	4.41E-16	-21.17
8	8460.02	25.50	4.54E-16	-21.14
9	8475.54	29.22	4.65E-16	-21.12
10	8489.29	25.70	4.79E-16	-21.09
11	8499.92	19.74	4.97E-16	-21.05
12	8506.40	11.94	5.21E-16	-21.00

Notes:
* indicates lag order selected by the criterion.
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion

Table 3.2 Cointegration Rank Test

Hypothesized No. of CE (s)	Eigenvalue	Trace Statistic	5% Critical Value	1% Critical Value
None**	0.06	97.51	76.07	84.45
At most 1	0.03	44.79	53.12	60.16
At most 2	0.02	22.32	34.91	41.07
At most 3	0.01	10.14	19.96	24.60
At most 4	0.01	4.07	9.24	12.97

Hypothesized No. of CE (s)	Eigenvalue	Max Statistic	5% Critical Value	1% Critical Value
None**	0.06	52.72	34.40	39.79
At most 1	0.03	22.46	28.14	33.24
At most 2	0.02	12.18	22.00	26.81
At most 3	0.01	6.07	15.67	20.20
At most 4	0.01	4.07	9.24	12.97

Notes:
** denotes rejection of the hypothesis at the 1% level. Both the Trace and Max-eigenvalue tests indicate one cointegrating equation at both 5% and 1% levels.

Table 3.3 Johansen Cointegration Test

Adjustment coefficients (α's)

ΔSS10	0.0003
	(0.004)
ΔSLOPE	-0.02
	(0.01)
ΔCREDIT	0.01
	(0.003)
ΔLIBOR	0.04
	(0.01)
ΔDURATION	-0.01
	(0.01)

Normalized Cointegration Coefficients (β's)

SS10	SLOPE	CREDIT	LIBOR	DURATION	C
1.00	0.06	-0.97	-0.01	-0.10	1.01
	(0.17)	(0.21)	(0.08)	(0.10)	(1.15)

Note: Standard errors are in parentheses.

Table 3.4 Estimation Results for ΔSS_{10}

Cointegrating Equation	e_{t-1} (error correction term)
$SS10,_{t-1}$	1.00
$SLOPE_{t-1}$	0.06 (0.35)
$CREDIT_{t-1}$	-0.97 (-4.66)
$LIBOR_{t-1}$	-0.01 (-0.14)
$DURATION_{t-1}$	-0.10 (-0.98)
Constant	1.01 (0.88)
Independent Variables	**Error Correction Model**
e_{t-1}	0.0003 (0.08)
$\Delta SS10,_{t-1}$	0.20 (5.39)
$\Delta SS10,_{t-2}$	-0.16 (-4.01)
$\Delta SLOPE_{t-1}$	-0.02 (-1.16)
$\Delta SLOPE_{t-2}$	-0.02 (-1.09)
$\Delta CREDIT_{t-1}$	0.08 (2.12)
$\Delta CREDIT_{t-2}$	0.003 (0.08)
$\Delta LIBOR_{t-1}$	0.04 (2.36)
$\Delta LIBOR_{t-2}$	0.02 (1.40)
$\Delta DURATION_{t-1}$	-0.01 (-0.66)
$\Delta DURATION_{t-2}$	-0.002 (-0.11)

Note: t-statistics are in parentheses.

Figure 3.1: Swap Spreads

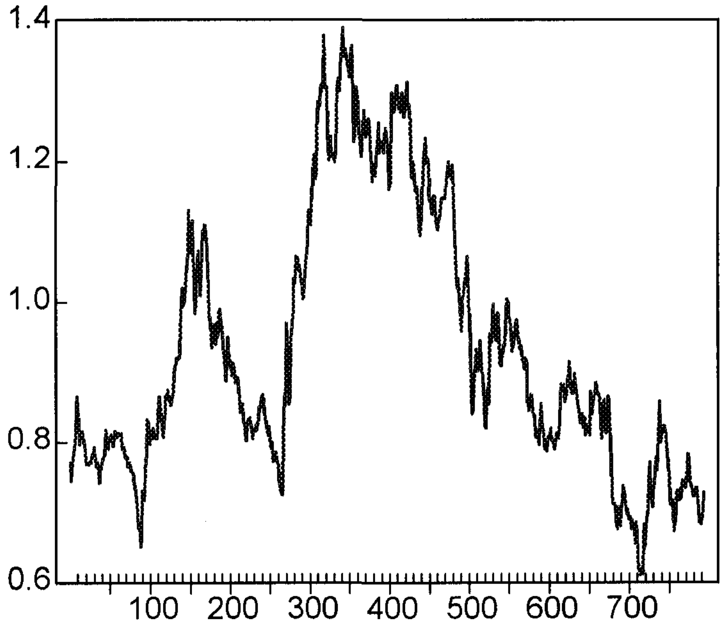


Figure 3.2: Slope of the Treasury Yield Curve

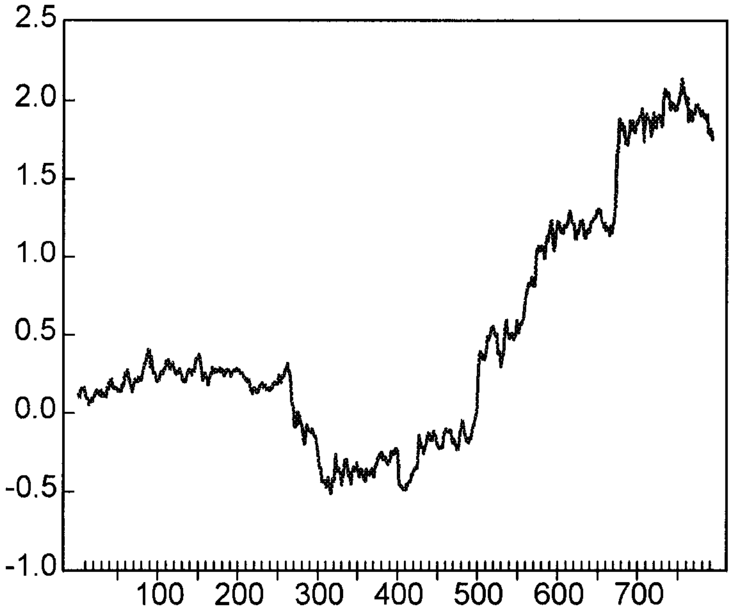


Figure 3.3: Six-month LIBOR

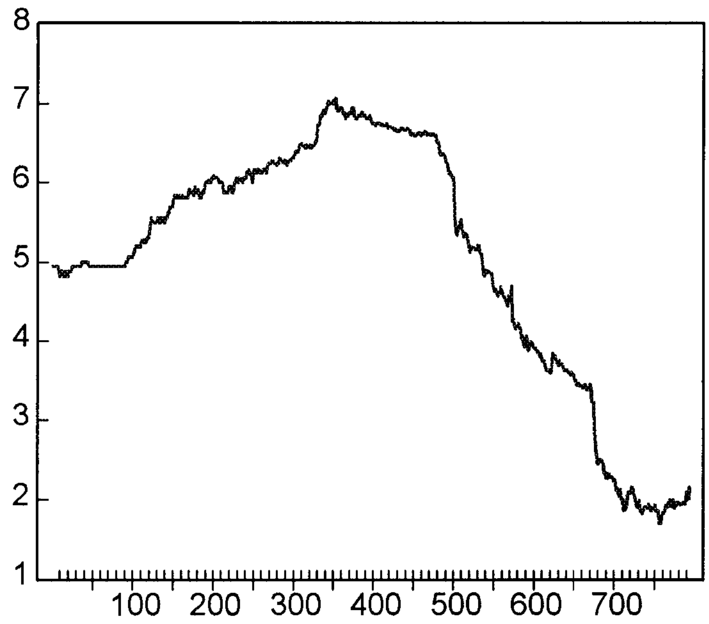


Figure 3.4: Credit Spreads of LUCI-A

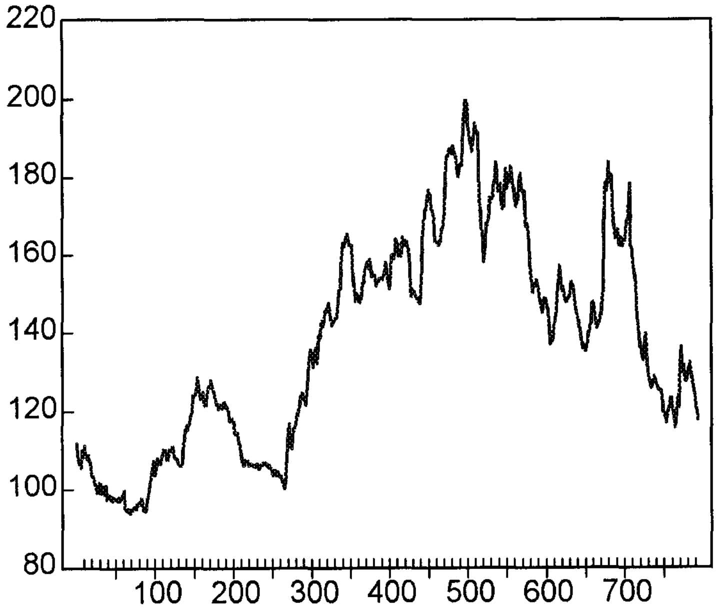


Figure 3.5: Modified Duration of LUCI-A

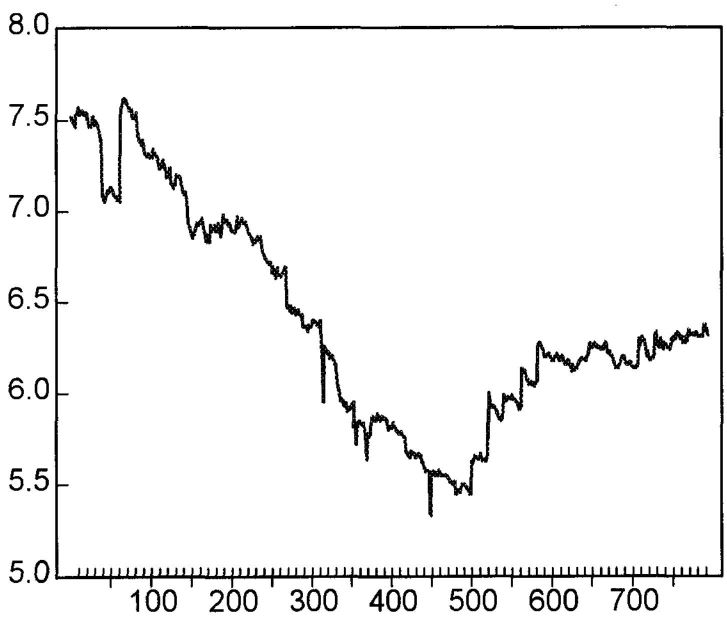
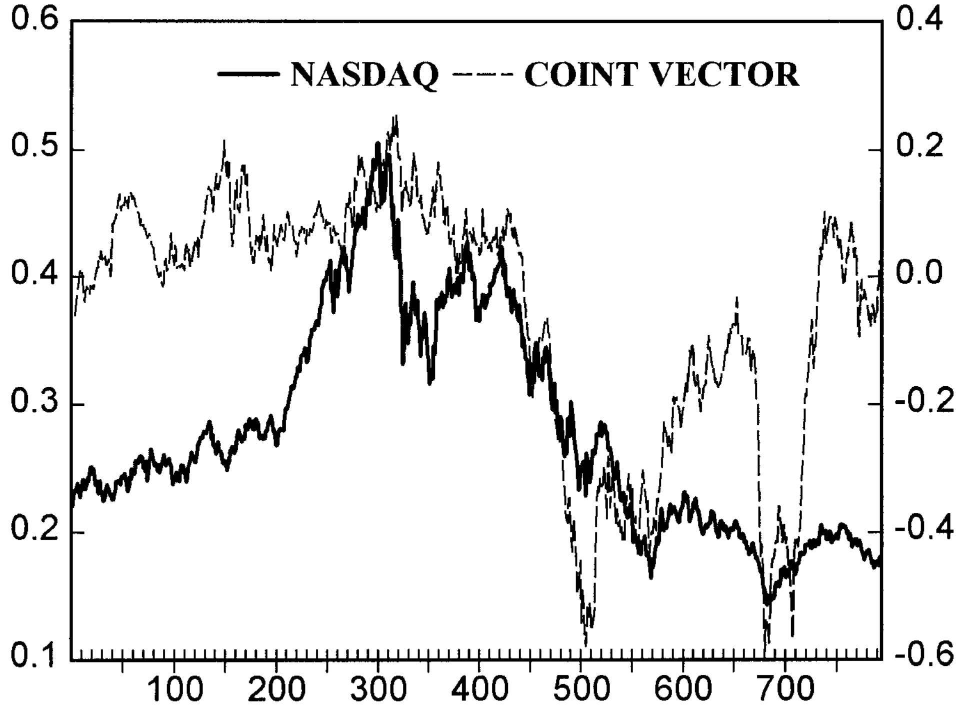


Figure 3.6: Nasdaq vs. Cointegrating Vector



Chapter 4

Swap Curve Dynamics across Markets

4.1 Introduction

Swap spreads consist of information that is fundamentally different than what one can obtain from sovereign yield curves. This information should constantly be monitored by policy makers, including central banks. In this study we provide evidence that supports this claim by studying the USD and HKD swap markets. We try to identify and then interpret the new information contained in the Hong Kong swap curve. Important policy implications are then discussed.

Swap curve has become the primary benchmark for assessing interest rate movements and should be at the center stage of risk management and risk monitoring activities. Yet, swap curve dynamics has not received much attention from researchers dealing with macroeconomic policy. Important information that may be contained in swap curve dynamics is often not taken into account when formulating monetary policy. Investigating these issues in the Hong Kong economy is particularly important given some special aspects of the Hong Kong financial markets.

A fundamental aspect of the Hong Kong economy is the so-called "peg" and the risks associated with it. Hong Kong dollar is pegged to the US dollar and the Hong Kong Monetary Authority (HKMA) acts as the currency board that preserves this peg. This constitutes the major feature of the Hong Kong financial markets. HKMA issues Exchange Fund Bills and Notes (EFBN) that are "direct, unsecured obligations of the Hong Kong Special Administrative Region Government for the account of Exchange Fund." The EFBNs can be used for trading, investment and hedging instruments. For example, those institutions that maintain Hong Kong dollar clearing accounts with HKMA can use their EFBN holdings to borrow O/N dollars from the discount window. HKMA has taken the necessary steps to create an active primary and secondary market that led to the creation of a *sovereign* benchmark yield curve for up to 10 years. This has facilitated the creation of a benchmark swap curve for the same maturity, although the swap curve contains significant additional information concerning the Hong Kong economy.

There are several interesting issues that emerge in this environment. Market professionals and economists attribute the difference between the USD and Hong Kong *sovereign curves* to the existence of the "peg". However, the differences between the *swap curves* of the two currencies may be due to several other important factors that may be as important as the peg and may have relevance for monetary policy. The rich data set concerning swap curves permits a detailed study of these issues and this is an attempt in that direction.

In the next section we provide a brief discussion of the main parameters of Hong Kong financial markets. Then in the third section we discuss the relevance of swap curves in tracking and monitoring term structure related risks. Section 4.4 provides a theoretical setting for interpreting swap rates and the related floating rates. We obtain some pricing formulas and show the important relationship between swap rates and the "aggregate credit risk" of a private economy. Section 4.5 deals with the data set and the empirical evidence. Finally, Section 4.6 summarizes our main findings and the relevant policy implications.

4.2 Background for Hong Kong markets

Hong Kong has a currency board regime administered by the HKMA, which was set up during the year 1993. The HKMA manages actively Hong Kong's official reserves that are called "Exchange Fund". The composition of the assets of HKMA can be altered at the discretion of Exchange Fund management. The assets of the Exchange Fund are substantial.[24] The possibility of entering the markets to change the composition of such a portfolio may have significant impact on the underlying rates and returns. This makes the Exchange Fund a major player in world financial markets.

4.2.1 Debt securities

One way to visualize the swap curve is to begin with a benchmark sovereign curve and then add to this a proper swap spread which results from a liquid interest rate swap market. In case of Hong Kong a benchmark sovereign curve can be obtained from the secondary market trading of the Exchange Fund Bills and Notes (EFBN). Exchange Fund Bills have short maturities of 1 week, 91, 182 and 364 days and are auctioned in form of public tender on a regular basis. They are quoted on an ACT/360 basis. The Exchange Fund Notes have longer maturities of 2, 3, 4, 5, 7 and 10 years and are quoted on an ACT/365 basis. The HKMA has established a set of official fixings for these securities.[25]

[24] The size of the balance sheet of HKMA was over HK$961 billion (over US$100) at the start of 2003. More than 90% of the assets were denominated in foreign currencies.
[25] The fixings are calculated using the arithmetic mean of 8 mid-quotes from the market at 11:00 am, after excluding two highest and two lowest quotes.

These debt instruments are traded in a two-tier dealership scheme, where the HKMA appoints a number of Recognized Dealers that deal in the primary market and Market Markers that deal in the secondary market. These institutions are committed in supporting a liquid market in these securities.

These debt instruments can be used as collateral against overnight (O/N) borrowing, as margin collateral in Hong Kong Futures Exchange for trading stock index futures and options. More importantly for our purposes, these securities can be used as collateral in Honk Kong dollar repo transactions.[26]

The Exchange Fund Bills and Notes (EFBN) form part of the monetary base of Hong Kong. The other important elements of the monetary base are the Certificates of Indebtedness (CI), which are the backing for banknotes and coins and the aggregate balance of the banking system maintained at the HKMA for the purpose of clearing and settlements between banks and the HKMA. The currency board system in place requires that the foreign assets of the HKMA be greater or equal to this monetary base. HKMA does not issue banknotes.

The Hong Kong and Shanghai Banking Corporation Limited, Standard Chartered Bank and the Bank of China (Hong Kong) Ltd. issue banknotes on behalf of HKMA. When these banks issue banknotes they deliver the required amount of USD to obtain the Certificates of Indebtedness.

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[26] In addition to the Exchange Fund Bills and Notes, the HKMA extended its note issuance program to include debt securities issued by agencies such as Mass Transit Railway Corporation, Airport Authority, and the Kawloon-Canton Railway Corporation. These securities are labelled as "Specified Instruments" and are fungible with Exchange Fund securities. They can also be used as collateral in discount window borrowing. The other important debt issuing agency is the Hong Kong Mortgage Corporation (HKMC) which is owned by the Exchange Fund, issues debt securities and purchases mortgages. During the year 2002 the HKMC issued HK$15 billion (US$1.9 billion) of new debt and had a mortgage portfolio of HK$28 billion.

4.2.2 Swap markets

Hong Kong has a relatively liquid swap market. The floating rate in these swaps is 3-month Hibor (Hong Kong Interbank Offered Rate)[27] and has an ACT/365 day count basis. The fixed leg of swaps is also quoted ACT/365 and on a *quarterly* basis per year. Active tenors of the swap market would be 2 to 10 years and trading sizes would be HK$200 million. A typical bid-ask spread would be 10bp. The daily turnover would be around HK$9 billion and is significantly higher than that of HK$2.5 billion for the EFBNs.

According to market practitioners the HK swap curve is priced off the USD swap curve.[28] Market practitioners think that the differences arise mostly because of the risks associated with the currency peg. This, in fact, is one important issue in our study. In this study we claim that there may be significant effects other than risks associated in the currency peg that is involved in the USD-HKD swap differences.

Players in international markets express views on the Hong Kong peg through positions taken either with currency forwards, short end of the swap curves or with the long end of the swap curves. Although similar positions can be put in place using the EFBN and US Treasuries, market players do not prefer this approach. This may be due to balance sheet, funding and repoing costs that will be associated with dealing with EFBNs.

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[27] The rate of interest offered on Hong Kong dollar loans by banks in the interbank market for a specified period ranging from overnight to one year.
[28] See the very useful Deutsche Bank report on Hong Kong fixed income markets mentioned among the references.

One of the major players in the swap market is HKMA. With the yield curve being positively sloped, the HKMA has thus far preferred to swap the 10 year EFBN proceeds into floating rate funds. This means sudden demand for receiving fixed after issuance of a 10 year EFBN, which makes the 10 year swap rates go down and trade "tighter" for a while. This point is another issue that we investigate in this study. It is interesting to see which counterparties take the other side of such deals and what their objectives are. An analysis of these points may uncover some unseen risks in banking portfolios.

4.2.3 The Repo market

Unlike the USD market, there is no OTC repo market in Hong Kong. Short selling of EFBNs is limited to market makers. A player who shorts an EFBN has to cover this short position by entering into a one-day repo agreement with the HKMA. This could be done by exchanging the short security against a proper amount of other similar securities.

This structure of Hong Kong repo markets sets them apart from US dollar repos, which have a fundamentally different role to play in the US markets. Traders can use US dollar repo markets to fund their fixed income portfolios. Hong Kong repo markets' primary role is in guaranteeing the covering of short positions, in particular EFBNs. The structure of Hong Kong markets eliminates the notion of *special repo*. A short position in *any* EFBN can be covered overnight using this market. This eliminates many of the repo strategies that play an important role in European and US markets. In some sense, it "separates" the sovereign curve more from the Hibor and swap curves.

4.3 Swap curves are the "right" benchmarks

Analysis of macroeconomic policy is still done using the sovereign yield curve, reflecting the tradition of standard deterministic macroeconomic models. In the US the Treasury yield curve is used. In Hong Kong the benchmark yield curve is obtained from the EFBNs. Yet, in economies heavily dominated by private sector activities, sovereign yield curves have limited use. Swap markets provide benchmark yield curves that are much more appropriate for macroeconomic policy than the sovereign yield curves. There are several reasons for this.

We start with technical points. First, swaps are much more liquid than the sovereign bonds, even in Hong Kong markets, and at any time during the day one can obtain constant maturity par swap yields. Bond maturities on the other hand change as time passes and this leads to complicated numerical procedures to extract from observed bond trading data, the constant maturity yields that are needed for the curve. Second, bond trading data are not as homogenous as those from swap trading. There are repo specials and this may lead to prices that are out of line with the yield curve at any instant. Cleaning such "special" trades from observed data may not be possible. These are two technical reasons why swap yield curves can give more reliable estimates of the state of the true yield curve from a macro perspective. Third, bonds often contain implicit options that will distort their pricing. Decision makers need to calculate and then look at stripped yields.

However, substantial reasons for using swap curves are abound. In a private sector dominated economy the government's borrowing cost often has little relevance to macroeconomists. The more relevant cost of funds is what is paid by the aggregate private sector, after eliminating *the idiosyncratic default risk premia*. The swap curve reflects exactly this notion.

The swap spread, being the difference between the swap rate and the comparable maturity sovereign rate, measures some important variables that are critical for macroeconomists. First of all, swap spreads reflect an overall cost of *available liquidity* for the private sector companies, while sovereign yield curves contain imperfect information on this point. The slope of the sovereign yield curve is sometimes taken as a proxy for available liquidity. The higher the (positive) slope, the lower short term interest rates are compared to long rates. This may be contributed to Central Bank's stance on easing liquidity window. But, it may also be due to several other economic phenomena. One example is varying inflationary expectations or more importantly, views on volatility.

It turns out that convexity trades, may, depending on the level of volatility, influence the slope of the sovereign yield curve. For example, everything else being the same, an increase in long-term interest rate volatility will *decrease* long term yields and this would lower the slope of the yield curve. Such an event does not mean that market *liquidity* has increased; yet, using the slope of the yield curve would imply exactly this. Use of the swap spread as a measure of macroeconomic liquidity will avoid such problems.

In addition, when evaluating firm-wide credit risks, market practice is to look at spread to swaps rather than spread to Treasury benchmark curves. This eliminates anomalies due to Treasury actions. But such practice is also intended to partial out the effect of swap spreads that contains an economy-wide credit spread of the private sector. This way, market professionals are able to isolate the idiosyncratic credit risk that is particular to the individual firm's actions. But this implies at the same time the swap spread contains an "aggregate credit risk" that is priced in. For macroeconomic policy makers the relevant risk is this aggregate credit risk, not the idiosyncratic credit risks that will be averaged out in an aggregate setting.

4.3.1 The role played by liquidity

There are two different notions of liquidity that we need to deal with within this context. They are both critical from the point of view of financial markets. The first is the notion of liquidity used in the previous section. Central banks provide liquidity by means of adjusting the *money supply*. One measure of this liquidity is the relative cost of securing short-dated funds and this is what we discussed in the previous section. There is no doubt that this notion of liquidity, which, in a sense measures the stance of monetary policy, is important for financial markets. Economists often use the slope of the sovereign yield curve as a proxy for this notion of liquidity.

For financial market participants, the *liquidity* of the underlying security is also important. This notion of liquidity refers to the ease of buying and selling relatively large amounts of assets in ways that do not affect the market prices, and it measures the ease of transacting large deals. To the extent the market goes through periods of illiquidity, the absorption of large deals will take time and this would introduce some further volatility into the swap rates. There is no question that this notion of liquidity is also important for securing a smooth functioning of the financial markets.

4.4 Swap engineering

We now briefly discuss the financial engineering of swaps to obtain the necessary pricing equations. We focus on plain vanilla interest rate swaps.

Suppose that the interest rate swap is initiated at date t_o. A counterparty makes *n* fixed payments and will receive *n* floating payments at dates $t_1, \ldots, t_n$ in the same currency. The dates $t_1, \ldots, t_n$ are *settlement* dates and the $t_0, \ldots, t_{n-1}$ are *reset* dates. The latter are dates on which the relevant Libor (Hibor) rate will be redetermined.

The swap notional amount is denoted as *N* and let the floating rate tenor be represented by δ. Assume that the floating rate is 3-month Libor (Hibor), so that δ is 1/4. Fixed swap rate will be given as s_{to} and the Libor rates will be $\{Lt_o, \ldots, Lt_{n-1}\}$, respectively. The *swap spread*, w_{to} will be the difference between s_{to} and the yield on the sovereign bond with the same maturity. This sovereign yield is denoted by y_{to}.[29] That is,

$$w_{to} = s_{to} - y_{to} \tag{4.1}$$

Such a swap can be reverse-engineered in different ways.

- One can first decompose the swap into two streams of cash flows, one representing a floating stream of payments (receipts), the other a fixed stream. If this is done, then each stream can be interpreted as representing various types of bonds.

[29] This could be any interest rate accepted as a benchmark by the market.

- Second, one can decompose the swap according to settlement dates, slicing it into *n* cash exchanges during *n* time periods. If this is done, then each cash exchange can be interpreted as a Forward Rate Agreement, or FRA-in-arrears, with a special characteristic that the FRA rate is constant across different settlement dates.

Both approaches above will generate the same swap pricing formula. We choose to use the second approach because it is easier and it displays some interesting aspects of swap rates better. At time $t_i + \delta$, Forward Rate Agreement (FRA) counterparties will exchange the following cash flow:

$$[\, F(t_o,t_i) - Lt_i \,]\, \delta\, N \tag{4.2}$$

where N is the notional amount and the $F(t_o, t_i)$ is the FRA rate determined at time t_o. Note that this amounts to exchanging the fixed payment $F(t_o,t_i)\, \delta\, N$ against the floating payment $Lt_i\, \delta\, N$.

Now consider the relationship between the fixed swap rate s_{to} and the FRA rate. We see that the FRA rate $F(t_o, t_i)$ is determined independently from the s_{to}, either by supply and demand or by pricing through money markets. In general,

$$F(t_o, t_i) \neq s_{to} \tag{4.3}$$

This means that if we buy the *i*th swap cash flow and sell the cash flow implied by the *i*th FRA, the Libor (Hibor) payments will cancel out, but the fixed payments won't since they are *not* equal. As a result, this portfolio will end up with a *known* negative or positive net cash flow at time t_{i+1}. Since this cash flow is known exactly at time t_o, and there is no credit risk, this portfolio *must* have a known present value at time t_o. This present value will equal:

$$B(t_o, t_{i+1})\, [\, F(t_o, t_i) - s_{to} \,]\, \delta\, N \tag{4.4}$$

where the $B(t_o, t_{i+1})$ is the current value of a default-free zero coupon bond that matures at time t_{i+1}, with par value of one HK dollar. This expression tells us that the present value will be positive or negative depending on whether $F(t_o, t_i) > s_{to}$ or not. Of course, this should be true for all the elements of the swap individually. Also swap cash flows *altogether* need to have zero present value. This yields an important pricing relationship:

$$\sum_{i=0}^{n} B(t_0, t_{i+1})[F(t_0, t_i) - s_{t0}]\delta N = 0 \tag{4.5}$$

From here, rearranging the equation we could get a formula that ties the swap rate to the forward rates:

$$s_{t0} = \sum_{i=1}^{n} \omega^{i}_{t0} F(t_0, t_i) \tag{4.6}$$

This formula is important because it shows a relationship between the floating forward Libor (Hibor) payments and the relevant swap rates.

4.4.1 Interpreting Hibor and swap rate interactions

A swap involves exchanges of cash flows. But cash flows are generated by assets, liabilities, and other commitments. This means that swaps are simply a standardized, liquid, and cost-effective alternative to trading cash assets. Instead of trading the cash asset or liability, one can simply trade the cash flows generated by it. Because swaps in general have zero value at the time of conception and are very liquid, this key feature indeed makes them cost-effective alternatives. Hence their wide use in position taking, hedging, and risk management.

Formula (4.6) expresses the swap rate in terms of the forward rates and can be rewritten as follows:

$$s_{to} = \sum_{i=1}^{n} \omega^{i}_{t0} F(t_0, t_i) \tag{4.7}$$

where the ω^{i}_{to} are weights that add up to one, and they depend on the zero coupon discount bond prices:

$$\omega^{i}_{t0} = \frac{B(t_0, t_i)}{\Sigma_{j=1}^{n} B(t_0, t_j)} \tag{4.8}$$

As time passes these discounts will change and this will modify the weights ω^{i}_{to}.

First consider the stability of the weights ω^{i}_{to}. Parallel shifts in the yield curve will have relatively little impact on these weights. Significant changes in the slope of the yield curve can on the other hand modify the ω^{i}_{to} significantly. However, yield curve inverts rarely and this means that we can analyze the swap rate- forward rate relationship by acting as if these weights are relatively constant.

Under these assumptions we may interpret the swap rate as some type of *weighted average of forward rates*. Since forward rates can be regarded as (possibly biased) expectations of future Hibor rates that will be observed during respective swap settlement periods, the swap rate will be taken as a weighted average of the forward Hibor rates.[30]

Using equation (4.7) we can elaborate more on the Hibor-Swap rate relationship. Hibor is an average of the borrowing rates for twenty Hong Kong banks. It is also an interbank rate and applies to non-secured loans. The weighted average of the credit rating of the banks, from which the Hibor fixing is determined,

[30] However, these weights are not equal. In fact the ω^{i}_{to} will be declining, making the near Hibor rates play a more important part in determining the swap rates than the distant Hibor rates.

is likely to be around A+ or AA-. Thus Hibor rates L_{t+i} *will* incorporate some credit risk.

Suppose R_{ti} is the *term repo rate* in a *privately arranged* repo deal struck with an AAA-rated repo dealer with zero haircut and against general collateral made of EFBNs.[31] Then the Hibor and repo rates will be related according to:

$$L_{ti} = R_{ti} + c_{ti} \tag{4.9}$$

where c_{ti} is the credit risk spread between average A+ credits and sovereign credits.[32]

Using this relation we can rewrite the swap rate as:

$$s_{to} = \sum_{i=1}^{n} \omega^{i}_{t_0}\left[E^{\tilde{P}}_{t_0}[R_{t_i}] + E^{\tilde{P}}_{t_0}[c_{t_i}]\right] \tag{4.10}$$

where $\tilde{P}$ is an appropriate martingale probability. The first term in brackets is an average of expected repo rates and the second term is an average of expected future A+ credit spread.

All this means that the Hong Kong swap rate is expected to incorporate the following effects:

- The Hong Kong dollar is pegged to USD and hence, the USD Libor should have some significant effect on the Hibor. This effect will be independent of the average A+ credit risk premia that will move

[31] In Hong Kong such OTC repo markets do not exist. Yet, such a deal can always be structured.

[32] Note that accordingly a *typical* A+ credit is still going to command a positive credit default swap (CDS) rate, even though the theoretical CDS rate (cds_{ti}) for the *same n* periods and for the same *average* A+ credits will on the other hand be: $cds_{ti} = 0$. This should normally be the case since the CDS rate is quoted as a spread to the relevant swap rate. Yet, in reality, CDS contracts offer practicality, deliver options and liquidity to clients, and the CDS rates of individual banks will all be positive.

according to local variables in the two economies. Thus the correct way to model the relationship is to use the repo rates:

$$R_{ti} = R^{usd}_{ti} + p_{ti} \qquad (4.11)$$

where the R^{usd}_{ti} is the USD term repo rate for the same period and p_{ti} is the risk premium due to breakdown possibility of the currency peg. Under this characterization the p_{ti} will depend only on the currency peg and will be independent of any credit risk related factors.

- The Hong Kong swap rate is an average of expected Hibor rates and hence depends on the changes in the average credit risk for A+ rated credit. The movement of the average credit risk in Hong Kong should be independent of any movement in the USD sovereign curve.
- Hibor is a measure of short-term liquidity and in reality one would expect a *liquidity premium* to be priced in the forward rates. This liquidity risk should affect the swap rates as well.
- Finally, to the extent that there exists a significant counterparty risk in swap contracts, the swap rate would also depend on the changes in this swap counterparty risk. This clearly hinges upon whether the swap contract under consideration provides collateralization of positive or negative swap values during the maturity of the contract. Swap spread dynamics should provide information concerning the aggregate counterparty risks as well.

These relationships suggest the following hypotheses that can be tested using the available swap data for USD and HKD:

First, we expect Hibor to be significant in explaining Hong Kong swap rates. To the extent that Hibor rates are measures of HKD liquidity, they will play a role in determining Hong Kong swap rates. Second, we expect the US treasury curve to play a significant role in determining the Hong Kong swap rates. Both of these hypotheses are based on the consideration of the existence of the Hong Kong currency peg. Third, we expect the USD swap spreads *not* to determine the Hong Kong swap rates over and above the USD treasury curve and the USD Libor. This hypothesis is justified by the fact that, once liquidity and the peg effects are taken out, the USD swap spreads will essentially represent the average credit spread of the US economy and will be linked to the USD specific macroeconomic factors that affect liquidity. These effects should not influence Hong Kong swap rates over and above the Treasury curve and USD Libor. Finally, as the last hypothesis to be tested, we are interested in detecting if Hong Kong swap curve has a component that is exogenous to the USD related variables. In other words, credit spread changes of Hong Kong companies, local macroeconomic conditions may affect the Hong Kong dollar swap rates over and above what USD related variables and we would like to know if this is indeed the case.

4.5 Empirical evidence

4.5.1 Data

We investigate the above postulated hypotheses by looking at the data on (a) Libor, Hibor rates, (b) US Treasury curve, (c) US dollar swap spreads, and (d) Hong Kong dollar swap curve. The empirical work uses five maturities for the relevant curves, namely 3, 4, 5, 7 and 10-year tenors. The USD Libor and the Hibor have a 3-month tenor. The data are daily and cover the period of 1997 to 2003. For USD swap spreads we use semi-annual 360 day rates. Hong Kong swap rates are quoted on a quarterly 365-day basis and these differences require a small adjustment. The data are collected from Bloomberg.

4.5.2 Preliminary analysis of the sample data

Figures 4.1 displays the US dollar and the Hong Kong dollar swap curves over the sample period. Overall we see that the time series behavior of the two curves are quite similar except for the period of Asian financial crisis, when the Hong Kong swap rates spike for a period of about 290 trading days. Starting from the third week of October 1997 when the Hong Kong dollar came under speculative attack, the huge spike subsides by the end of 1998. After that period Hong Kong swap rates continue to be in sync with the USD swap rates.

The swap term structure for Hong Kong and the US during the same sample period is constructed in Figure 4.2. We see that the Hong Kong swap rates are, for this particular sample period, on the average 110 basis points higher than the USD swap rates at the 10 year maturity. It decreases to about 75 basis points at the 1 year maturity. This difference can be found as "too large" by market practitioners who are used to swap rate spreads of around 40-50bp for USD and HKD. But, it must be remembered that our sample does contain the period of Asian financial crisis and for about 200 days the USD and HKD swap spreads diverged by more than 300 basis points. Excluding this period leaves a spread of around 40-45bp. However, it may not be appropriate to exclude the Asian crisis since it is a period of legitimate turbulence that has a great of relevance for monitoring the risks associated with the currency peg.

Figure 4.3 shows the time series on the difference between the USD and HKD swap rates at 5-year maturity. Our final preliminary investigation of the data concerns the second half of this figure. We see from this plot that the spread at the 5-year maturity between the USD and HKD swap rates has a positive trend. This is supported by a simple regression. Figure 3.4 provides the estimate of the simple regression on the subsample:

$$s^{hkd}_t - s^{usd}_t = \alpha + \beta t + \varepsilon_t \quad (4.12)$$

Here the s^{hkd}_t and s^{usd}_t are the 5-year USD and HKD swap rates; t is the time trend. Results indicate that there is indeed a significant positive trend in this swap differential over the subsample period between 2000 and 2003.

This is occurring during a period of deflationary pressures and relative calm in Hong Kong currency markets. The deflationary pressures have negative effects on default risk and the associated credit risk premia. The fact that the swap differentials are on the increase during a period where no questions were raised about the peg is a preliminary indication that swap spreads provide information on aggregate credit risks as well as on the peg breakdown risk.

4.5.3 Joint time series dynamics

To investigate the complex dynamics that exists between US Treasury curve, USD swap spreads, HKD swap curve and the Hibor, Libor rates, a linear Vector Autoregressive system is adopted. We let the Y^{usd}_t, sw^{usd}_t, s^{hkd}_t represent respectively the time-t *vectors* on the data concerning US treasury curve, USD swap spreads, and the Hong Kong swap rates. Each vector is 1 by 5. Let L^{hkd}_t, L^{usd}_t be the time-t Hibor and USD Libor rates respectively.

Then we can consider the following block linear system:

$$\begin{pmatrix} L^{hkd}_t \\ L^{usd}_t \\ Y^{usd}_t \\ sw^{usd}_t \\ s^{hkd}_t \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} & A_{13} & A_{14} & A_{15} \\ A_{21} & A_{22} & A_{23} & A_{24} & A_{25} \\ A_{31} & A_{32} & A_{33} & A_{34} & A_{35} \\ A_{41} & A_{42} & A_{43} & A_{44} & A_{45} \\ A_{51} & A_{52} & A_{53} & A_{54} & A_{55} \end{pmatrix} \begin{pmatrix} L^{hkd}_t \\ L^{usd}_t \\ Y^{usd}_t \\ sw^{usd}_t \\ s^{hkd}_t \end{pmatrix} + \begin{pmatrix} \epsilon_{1\,t} \\ \epsilon_{2\,t} \\ \epsilon_{3\,t} \\ \epsilon_{4\,t} \\ \epsilon_{5\,t} \end{pmatrix} \tag{4.13}$$

In this model the A_{1j}, j = 1, ..., 5, is a 1 by 5 row vector of coefficients made of *lag operators*.[33] Similarly for the A_{2j} to A_{5j}, j = 1, ..., 5. These coefficients show how the variables under consideration affect the Libor rates. The coefficients of interest to us are the A_{5j}, j = 1, ..., 5. These are 5 by 5 matrices of coefficients showing how the underlying variables affect the Hong Kong swap rates.

In particular, the $A_{5,1}$ is a vector showing the impact of Hibor on the Hong Kong swap curve. The $A_{5,2}$ is a vector of coefficients showing how USD Libor affects the Hong Kong swap curve. The other three vectors of coefficients can be interpreted as follows. The $A_{5,3}$ describes the effect of the US treasury curve on the Hong Kong swap curve. Similarly the $A_{5,4}$ indicates the effect of the US swap spreads on the Hong Kong swap curve and finally, the $A_{5,5}$ tells us how the past history of Hong Kong swap rates influences itself. The hypotheses discussed in this study suggest that:

- Hypothesis 1. The peg is relevant in determining the Hong Kong swap rates, as expected by everybody, the US treasury curve will be significant and that:

[33] The current lag has zero coefficient.

$$A_{5,3} \neq 0 \quad (4.14)$$

- Hypothesis 2. The USD swap spreads do not affect Hong Kong swap rates over and above USD sovereign curve, we would have:

$$A_{5,4} = 0 \quad (4.15)$$

- Hypothesis 3. Hong Kong swap rates contain useful information that is independent of the USD Treasury or swap curves, then:

$$A_{5,3} \neq 0 \quad (4.16)$$

Tables 4.1 to 4.3 summarize the results of testing these hypotheses using the model shown in (4.13) along with the data described above. In the version of the model reported here we used 5 lags. The use of 10 or 15 lags does not change the general pattern of the results, while consuming a lot more degrees of freedom.

With regard to the first hypothesis, consider the F-tests reported in Table 4.1. We see that these tests are *very* significant, in other words, the US treasury curve has a strong impact on the time series dynamics of Hong Kong swap rates. Given the existence of the currency peg this is not a very surprising result.

The more interesting result emerges from hypothesis 2. Table 4.2 reports the sum of squares of restricted and unrestricted regressions that test the hypothesis that $A_{5,4} = 0$. We see that according to the data used here USD swap spreads have *no impact* on the Hong Kong dollar swap rates once the effect of the US treasury curve and the effect of short term liquidity is taken into consideration. This is consistent with our hypothesis that swap spreads contain macroeconomic information concerning the aggregate credit risk of the domestic firms in a given economy.

Tests on the third hypothesis can be found in block exogeneity tests in Table 4.3, which in fact contains all the relevant significance levels concerning the F-test statistics on the feedbacks between the variables in system (4.13). The table can be regarded as a direct estimate of the significance of all the A_{ij}, $i = 1, ..., 5$; $j = 1, ..., 5$. The main point is that the sub-block of coefficients that show the effect of past Hong Kong swap rates on the current swap rates is quite significant with complex dynamics. It indicates that even after taking into account the US treasury curve and the liquidity effect through Hibor and Libor, Hong Kong swap rates are still informative on the Hong Kong economy.

4.5.4 Additional empirical work

A few other procedures are tried on the swap data. In particular we look at the impulse response functions for Hong Kong swap rates to the variables shown in Table 4.3. In general, results are consistent across different length of maturities. Impulse responses for the 5-year HKD swap rates are presented in Figure 4.5 and Figure 4.6. They allow us to detect the contemporaneous and ensuing impacts from all the variables on Hong Kong swap rates. Each graph reveals the responses of the 5-year Hong Kong swap rates when a one-standard-deviation innovation is imposed on one of the variables in the system. We trace out the responses of the 5-year Hong Kong swap rates over a period of 100 days after the initiation of the shock.

The results confirm the main conclusions that we report in Tables 4.1- 4.3. USD swap spreads and Libor are uncorrelated with HKD swap rates once the effects of US Treasury curve and Hibor are filtered out. The most prominent effects that can be observed are from the 3-year US Treasury, the 3-year and 5-year HKD swap rates, and the relevant effects are statistically significant.

Now, we re-run the same regression only for the period from the third week of October 1997 to early December 1998 and perform Granger causality tests, since it is of special importance to check whether the above regression results hold for the Hong Kong market during the Asian financial crisis. Table 4.4 shows the results under the null hypothesis that the probability of each of the 17 variables Granger-causing Hong Kong swap rates is zero. As can be seen, only 4-year US Treasury rate and 3-year Hong Kong swap rate itself would Granger-cause 3-year Hong Kong swap rate at 1 percent significance level. No other variables are detected to exert Granger-causality impact on the Hong Kong swap rates. Surprisingly, during this sub-sample period when Hong Kong was hit by the Asian crisis, regression results would not generally support hypotheses 1 and 3. But, we need to keep in mind that this is an extreme time period when different sectors of the Hong Kong economy experienced disruptions in terms of liquidity or solvency.

4.6 Conclusions

In this study we have examined the extent of swap curve dynamics across USD and HKD markets. Our main concern is to see whether Hong Kong swap curve contains a component that is exogenous to the USD related variables. We test three essential hypotheses in order to explore the relationships among USD Treasury curve, USD swap spreads, HKD swap curve, Hibor and Libor rates by mainly adopting block exogeneity tests and impulse response functions.

The following conclusions have been derived from our analysis: (a) due to the existence of the Hong Kong dollar peg system, US Treasury curve invokes significant responses on HKD swap curve; however (b) both USD swap spreads and Libor fail to provide valuable information on the dynamics of HKD swap rates; (c) as expected, Hibor rates play a role in determining Hong Kong swap rates; and (d) most importantly, Hong Kong swap curve itself contains rich information over and above that provided by the sovereign yield curve and the standard measures of market liquidity.

The findings of this study and their implications suggest that using sovereign yield curves and concentrating only on the risk premium associated with the breakdown of the currency peg is not sufficient for policy making in Hong Kong. With a component that is exogenous to the USD related variables, Hong Kong swap spreads and swap curves should be carefully monitored in order to assess economy wide risks and to conduct macroeconomic policy.

4.7 References

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Table 4.1 US Treasury yields do influence HKD swap rates

Maturity	F- Test
3 year	3310.0
4 year	2557.0
5 year	1853.0
7 year	1642
10 year	1417

Table 4.2 USD swap spreads do not influence HKD swap rates

Maturity	Unrestricted	Restricted	F-Test
3 year	0.0141	0.0143	0.90
4 year	0.0109	0.0111	0.96
5 year	0.0091	0.0093	1.18
7 year	0.0073	0.0075	1.57
10 year	0.0069	0.0070	0.96

Table 4.3 Block Exogeneity Tests

Variable	1	2	3	4	5	6	7	8	9
HIBOR	0	0	0.20	0.54	0.98	0.97	0.88	0.66	0.72
LIBOR	0.61	0	0.01	0.31	0.64	0.65	0.16	0	0.02
UST 3	0.76	0.24	0	0.12	0.44	0.08	0.20	0.06	0.59
UST 4	0.95	0.15	0	0	0.31	0.02	0.29	0.15	0.61
UST 5	0.89	0.04	0.01	0.71	0.35	0	0.39	0.30	0.69
UST 7	0.88	0.17	0.04	0.43	0.31	0	0.94	0.32	0.60
UST 10	0.92	0.12	0.52	0.64	0.07	0.04	0	0.41	0.90
US 3SS	0.33	0.14	0.14	0.21	0.44	0.52	0.40	0	0.14
US 4SS	0.42	0.05	0.58	0.55	0.14	0.81	0.40	0	0
US 5SS	0.59	0.06	0.64	0.88	0.23	0.43	0.83	0.06	0.45
US 7SS	0.59	0.12	0.37	0.55	0.13	0.19	0.19	0.68	0.69
US 10SS	0.84	0.04	0.22	0.73	0.47	0.22	0.49	0.15	0.30
HKS 3	0	0.76	0.32	0.68	0.42	0.85	0.49	0.43	0.45
HKS 4	0	0.92	0.73	0.67	0.37	0.75	0.53	0.60	0.54
HKS 5	0	0.90	0.86	0.34	0.17	0.46	0.24	0.88	0.45
HKS 7	0	0.91	0.97	0.26	0.05	0.19	0.05	0.85	0.46
HKS 10	0	0.95	0.98	0.29	0.03	0.17	0.02	0.95	0.65

Variable	10	11	12	13	14	15	16	17
HIBOR	0.72	0.73	0.84	0	0.06	0.69	0.10	0
LIBOR	0.51	0.54	0.76	0	0	0.45	0.95	0.95
UST 3	0.12	0.14	0.80	0.38	0.17	0.29	0.97	0.83
UST 4	0.06	0.18	0.95	0.30	0.32	0.44	0.99	0.88
UST 5	0.01	0.18	0.96	0.35	0.55	0.51	0.96	0.80
UST 7	0.03	0.06	0.97	0.33	0.46	0.36	0.97	0.88
UST 10	0.24	0.21	0.85	0.42	0.62	0.36	0.92	0.90
US 3SS	0.05	0.21	0.71	0.52	0.55	0.50	0.57	0.17
US 4SS	0	0.29	0.22	0.68	0.78	0.62	0.46	0.19
US 5SS	0	0.10	0.18	0.33	0.53	0.67	0.25	0.59
US 7SS	0	0	0	0.65	0.85	0.77	0.24	0.11
US 10SS	0.04	0.41	0	0.48	0.80	0.84	0.74	0.68
HKS 3	0.95	1.00	0.90	0	0	0	0	0.11
HKS 4	0.82	0.98	0.93	0	0	0.01	0	0.31
HKS 5	0.78	0.99	0.68	0.12	0	0	0	0.23
HKS 7	0.64	0.97	0.39	0.02	0	0	0	0.06
HKS 10	0.47	0.94	0.22	0	0.04	0	0	0

Notes:

(1) This table is split into two parts. The bottom part is a continuation of the upper.

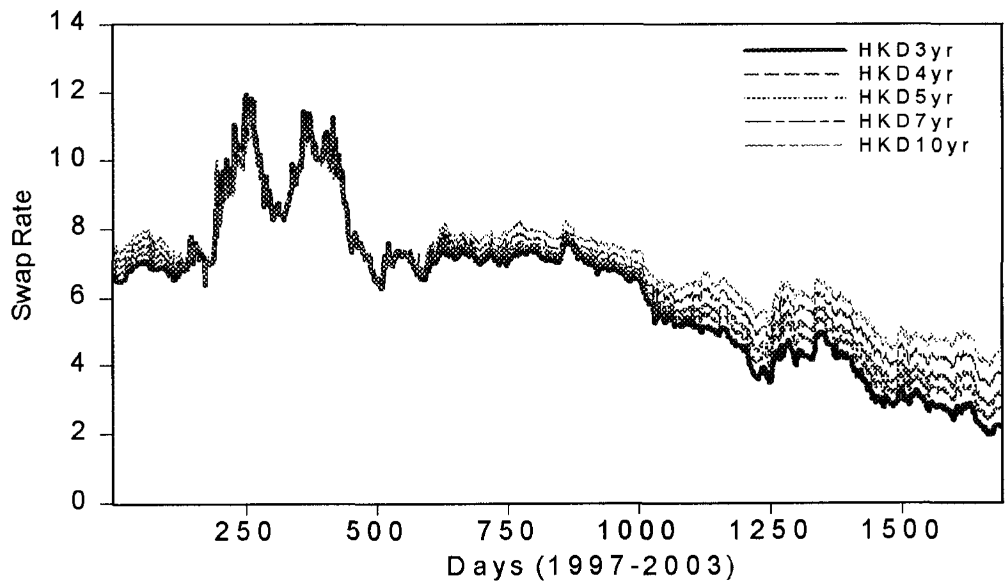
(2) The seventeen variables are respectively: HIBOR, LIBOR, 3-, 4-, 5-, 7-, 10-year US Treasuries, 3-, 4-, 5-, 7-, 10-year US dollar swap spreads, and 3-, 4-, 5-, 7-, 10-year HK dollar swap rates.

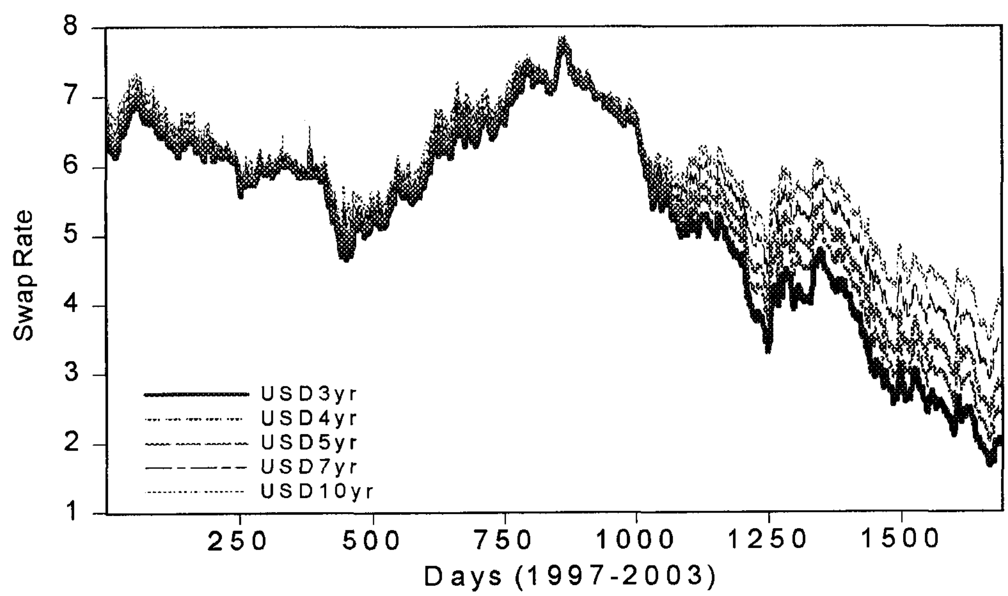
Table 4.4 Granger causality probabilities for HKD swap rates during the Asian financial crisis

	3 year	4 year	5 year	7 year	10 year
HIBOR	0.38	0.38	0.31	0.36	0.33
LIBOR	0.11	0.12	0.13	0.28	0.42
UST 3	0.71	0.79	0.83	0.60	0.51
UST 4	0.01	0.05	0.23	0.38	0.68
UST 5	0.57	0.54	0.45	0.60	0.65
UST 7	0.57	0.74	0.73	0.79	0.80
UST 10	0.54	0.65	0.52	0.56	0.58
US 3SS	0.58	0.50	0.54	0.54	0.46
US 4SS	0.64	0.61	0.78	0.76	0.64
US 5SS	1.00	0.99	1.00	0.97	0.91
US 7SS	0.71	0.82	0.79	0.80	0.82
US 10SS	0.67	0.71	0.62	0.87	0.91
3 year	0.01	0.13	0.54	0.43	0.36
4 year	0.12	0.16	0.58	0.49	0.52
5 year	0.34	0.49	0.31	0.31	0.21
7 year	0.31	0.26	0.15	0.04	0.11
10 year	0.14	0.25	0.13	0.11	0.18

Note: The probabilities in the columns reflect the Granger-causal impact of all the variables on the 3-year, 4-year, 5-year, 7-year and 10-year Hong Kong swap rates.

Figure 4.1 HK Dollar Swap Curve and US Dollar Swap Curve





Note: Maturities of 3, 4, 5, 7 and 10 years are used in the study.

Figure 4.2 Term Structures of Swap Rates, US vs. HK (1997-2003)

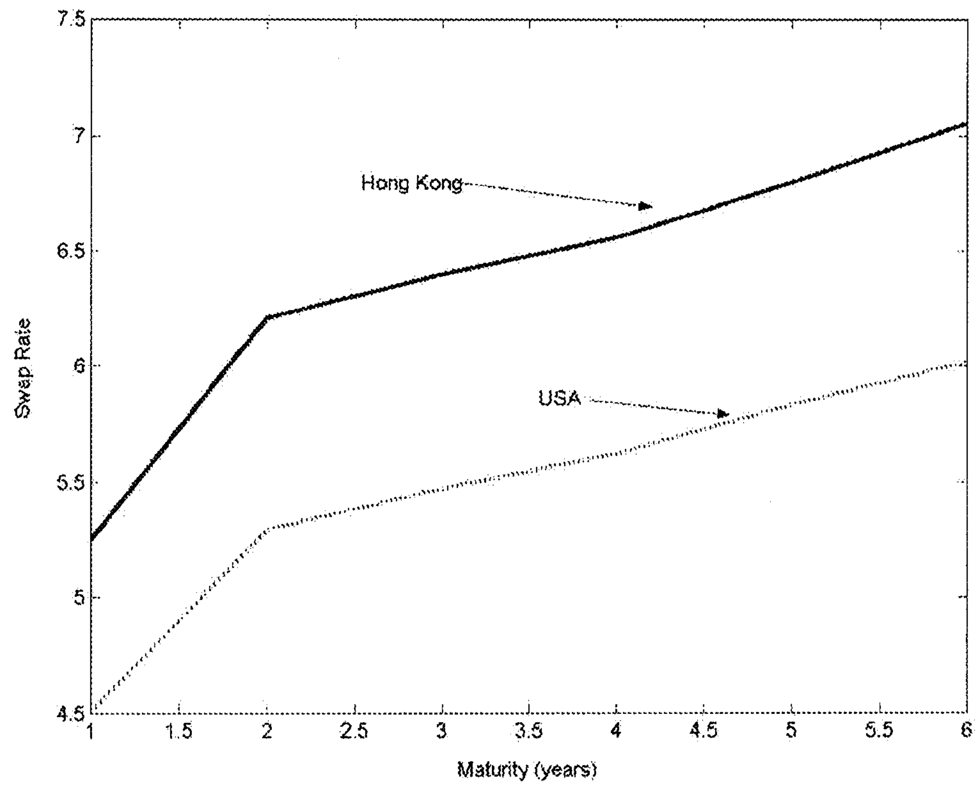


Figure 4.3 Difference Between 5-year HKD and USD Swap Rates

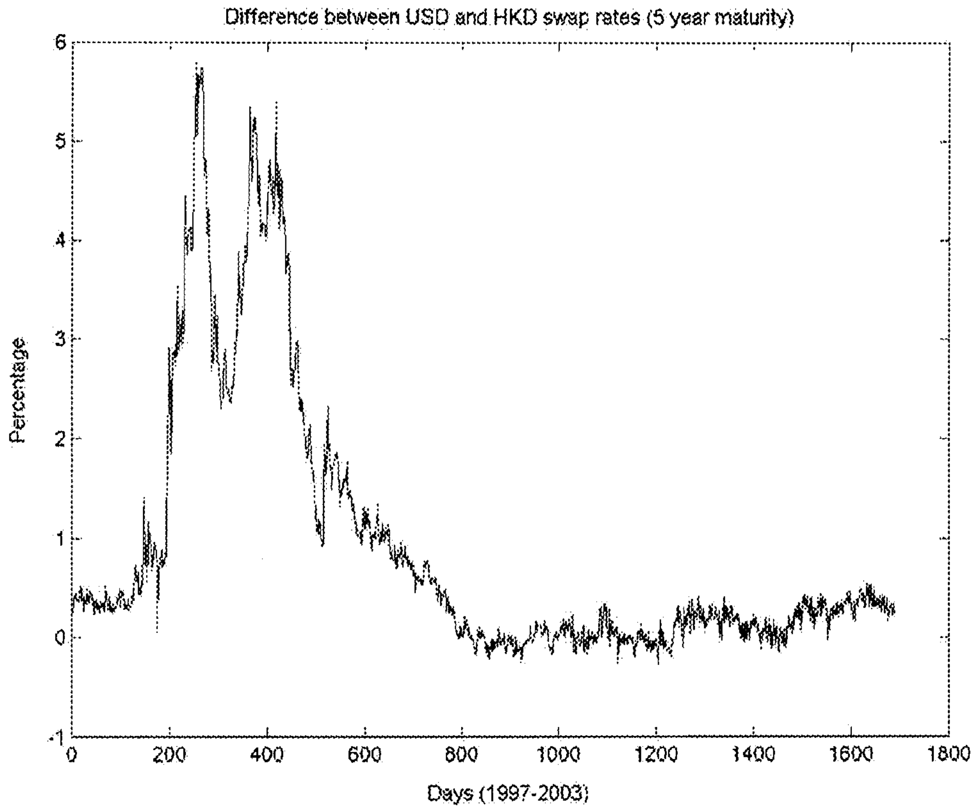


Figure 4.4 HKD vs. USD 5-year Swap Rates (subsample)

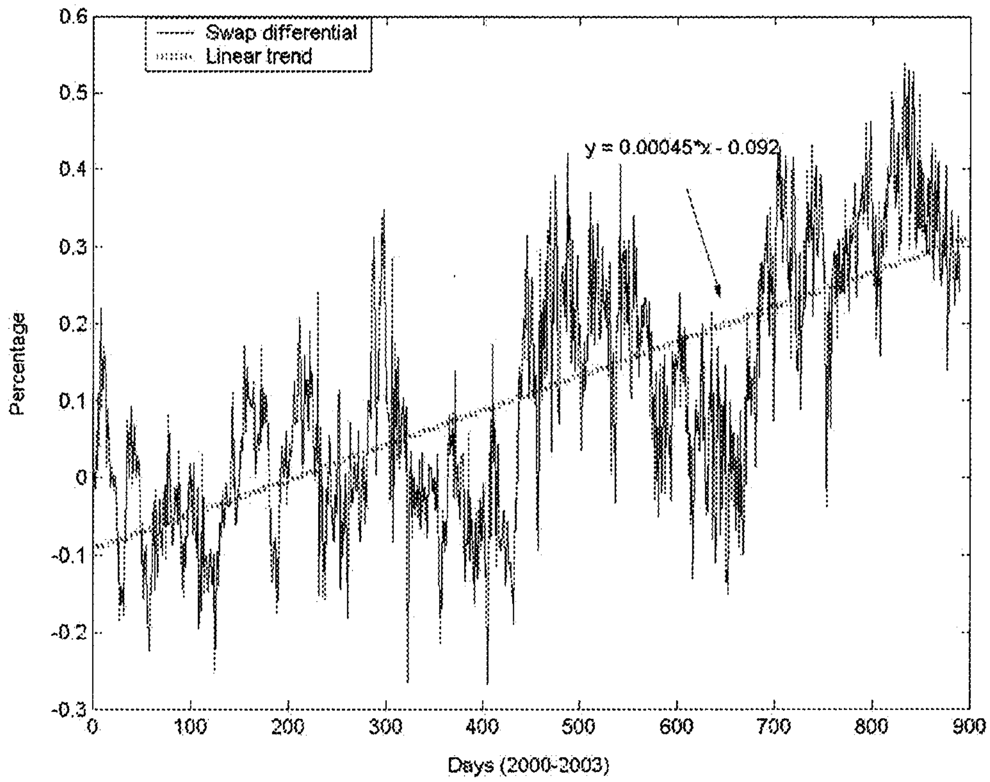
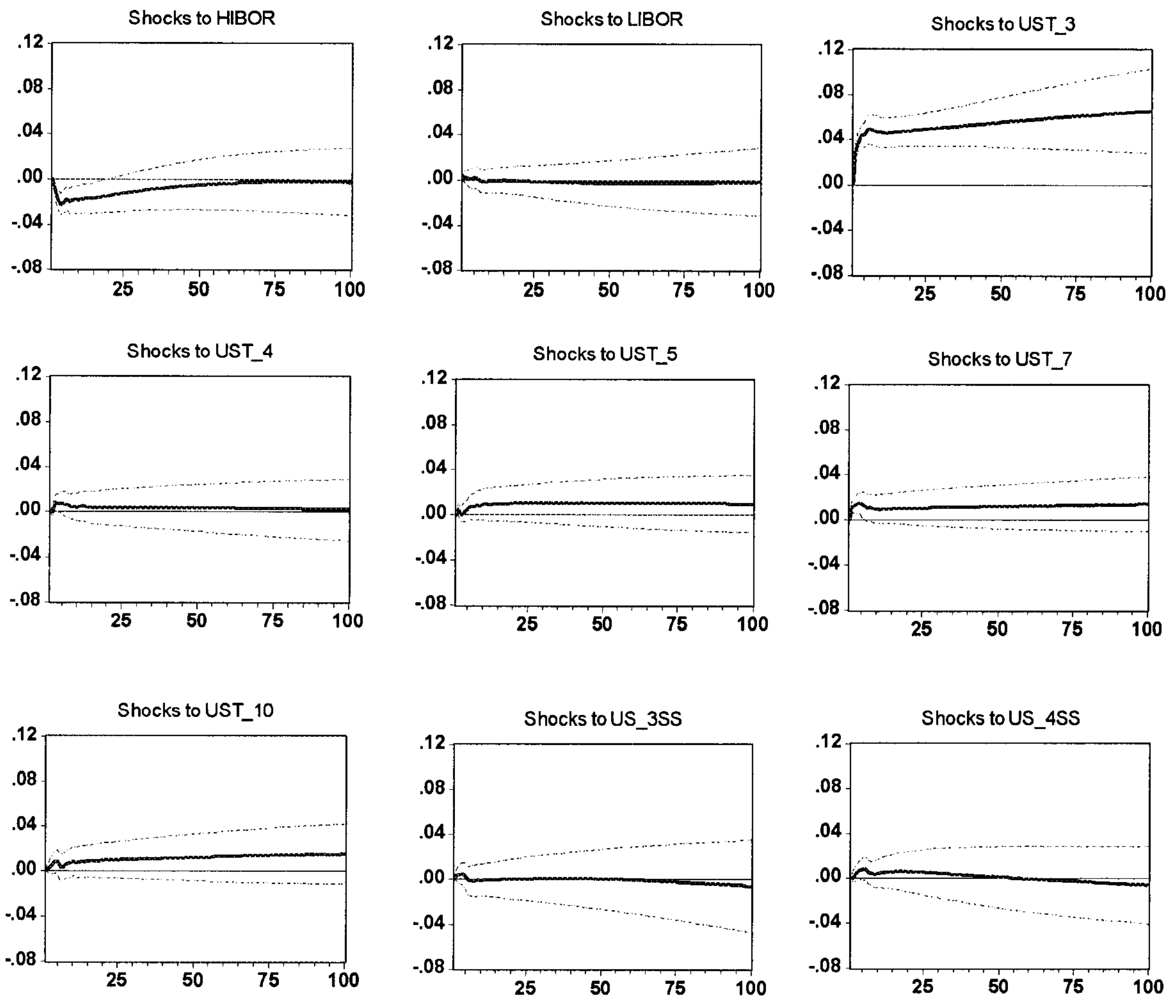
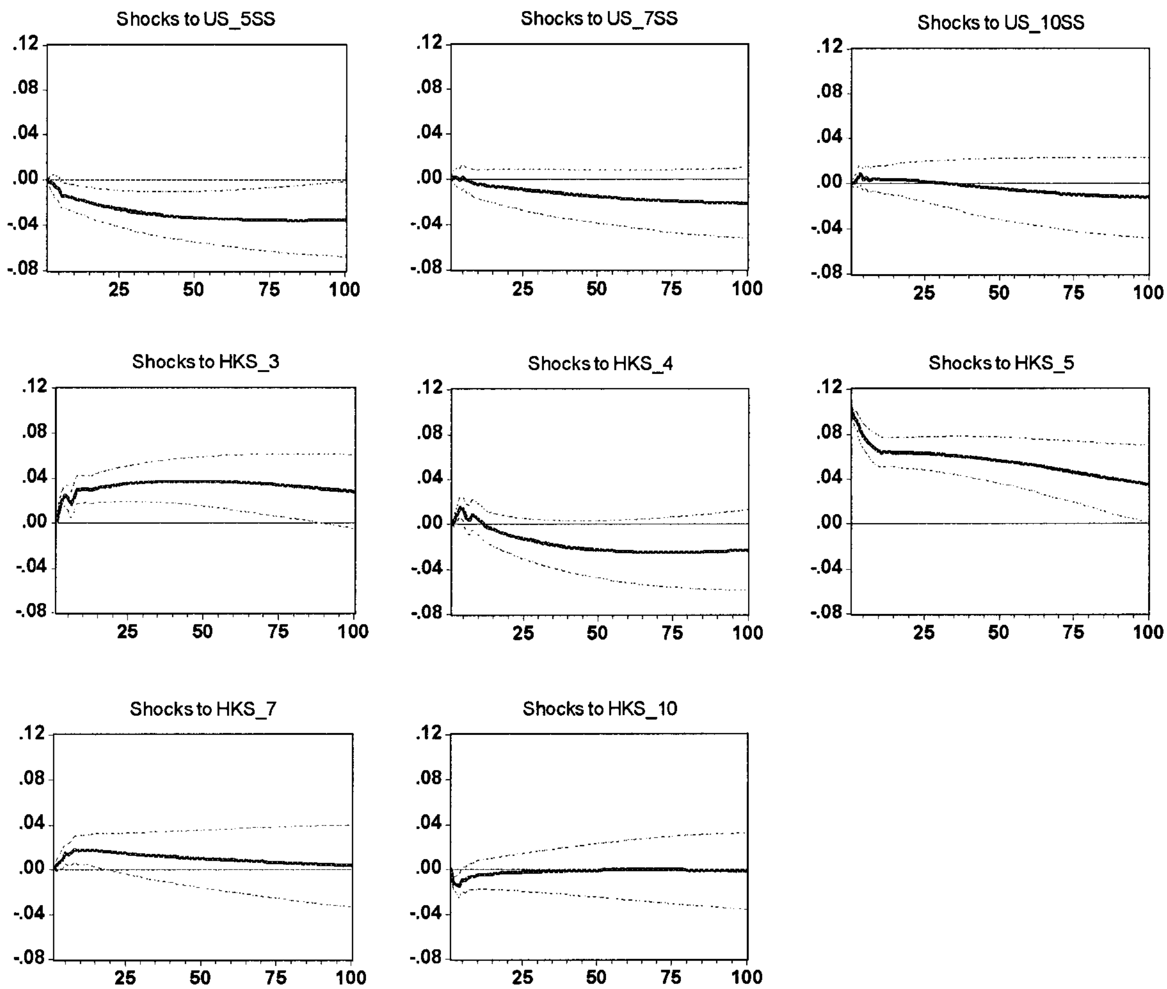


Figure 4.5 Impulse Response Functions



Notes: A seventeen-variable VAR is estimated. Each small graph shows the responses of Hong Kong swap curve (5-year tenor) to the shock imposed on each variable over a period of 100 days. Estimations are done by Monte Carlo method. Plus/minus two standard deviation bands (dashed lines) are displayed along with the impulse responses. The variables are respectively 3-month HIBOR, 3-month LIBOR, US Treasuries, US dollar swap spreads, and Hong Kong dollar swap rates all with 3, 4, 5, 7, 10-year maturities.

Figure 4.6 Impulse Response Functions (continued)



Chapter 5

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