Term Structure of Interest Rates in the Singapore Asian Dollar Market

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TERM STRUCTURE OF INTEREST RATES IN THE SINGAPORE ASIAN DOLLAR MARKET

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SUMMARY
This paper investigates empirically the term structure of interest rates in the Singapore Asian Dollar Market. We consider extended versions of the ARCH-M model of Engle, Lilien, and Robins (1987). The extended models permit autocorrelation, skewness and leptokurtosis in the residuals. The robustness of the empirical tests with respect to alternative specifications of the ARCH process is examined. It turns out that there is significant time-varying term premium, and this conclusion is independent of the hypothesized ARCH model.

1. INTRODUCTION
The term structure of interest rates has been a much-researched area in economics and finance. It is of interest to financial economists because it provides useful information about the existence of intertemporal arbitrage opportunities and sheds light on the efficiency of financial markets in utilizing information to form expectations. At the macroeconomic level it is important to monetary authorities if they know whether the interest rate term structure can be altered to desirably affect short-term international capital flows, while at the same time encouraging long-term domestic investment. Thus, understanding the term structure of interest rates forms the basis for policy recommendations such as the ‘Operation Twist’ (Malkiel, 1966).

For use in analysis the term premium of interest rates is usually defined as the forward rate minus the corresponding expected future spot rate (see, e.g., Nelson 1979). The behaviour of the term structure of interest rates can then be translated into statements concerning the term premium. Four basic hypotheses of the term structure of interest rates have been proposed in the literature. According to the expectations hypothesis the term premium is identically zero, which is the result of market equilibrium created by rational, risk-neutral and wealth-maximizing investors. The Hicksian liquidity premium hypothesis asserts that the term premium is positive. The basic assumption is that investors typically have short investment horizons. This implies that long-term yields should carry a risk premium over short-term yields. The preferred habitat hypothesis argues that the term premium may be positive or negative, depending on the investment horizons of investors. If investors are concerned with returns over a long time horizon, short-term bonds may be viewed more risky than long-term
bonds. Investors will thus demand a higher expected return on short-term bonds. According to the market segmentation hypothesis, the long- and short-term markets are unrelated and no particular statement can be made concerning the term premium. For further discussions on the theories of term structure, see Nelson (1979) and Ingersoll (1987).

There is a vast literature of empirical studies on these four hypotheses of the term structure of interest rates. In this paper we examine the term structure of the Singapore Asian Dollar Market, which was initiated in 1968 as a result of the spillover from the Eurodollar Market. The sterling crisis in Britain in the mid-1950s caused the British government to clamp control on non-resident sterling borrowing and lending by British banks. Institutions then turned to the US dollar for financing international trade, thus making it a major international currency. In October 1968 some American banks were granted permission by the Singapore government to set up currency units to attract Asian non-resident deposits to fund the banks' Asian lending activities. Special concessions were given by the Singapore government in exempting the withholding tax on offshore currency transactions, as well as granting a reduced tax rate of 10 per cent instead of the usual 40 per cent for income derived from offshore loans. On the other hand, the Regulation Q restricted the domestic interest rate American banks could pay on term deposits and widened the interest rates differential between the dollar in the US and other countries, attracting many American banks to operate in other financial centres. These factors contributed to the rapid growth of the Singapore Asian Dollar Market, whose year-end total assets grew from $30.5 million in 1968 to about $300 billion in 1989. This market holds the second-largest assets in Asia after Tokyo, and contributes significantly to making Singapore a major financial centre.

The methodology of this study is based on the approach of Hansen and Hodrick (1980, 1983) in their studies in foreign exchange markets. To circumvent the problem of unobservable expected future spot rate, we utilize the assumption of rational expectations. Thus, we model the error in forecasting the future spot rate based on the forward rate. The forecast error is regressed on a set of information variables, and the significance and signs of the regression parameters reflect the behaviour of the term structure. In order to have a powerful test we would want to use elements which are a priori likely to be important under the alternative hypotheses. Typical information variables are the yield spread (Mankiw and Summers, 1984) and forward premium (Hansen and Hodrick, 1980). Other components, such as ex-post term premium of various lags and returns of various maturities, are also considered by Leiderman and Blejer (1987).

The recent econometric literature has made two important contributions to this approach. Firstly, attention was focused on the specification of the error structure of the regression equation. The most notable contribution is perhaps the autoregressive conditional heteroscedastic (ARCH) model by Engle (1982). This model is motivated by the empirical finding that for some economic variables large changes tend to be followed by large changes, and small changes tend to be followed by small changes. Bollerslev (1986, 1987) further extended the ARCH model to the generalized ARCH (GARCH) model that allows the current conditional variance to be a function of past conditional variances. He also suggested that models with errors are distributed conditionally as Student's t. Secondly, an innovative idea was proposed by Engle, Lilien, and Robins (1987), to allow the conditional variance to affect the mean, resulting in the ARCH-M model. These authors found that the conditional variance is a significant information variable affecting the excess holding yield.

In this paper we consider ARCH-M models that extend the error process to more flexible structures. Preliminary ordinary least-squares results show that the residuals, as well as the squares of the residuals, may be autocorrelated. Thus, an ARCH type model that can
incorporate residual autocorrelation is proposed. Following Bollerslev (1987) we propose an error distribution which deviates from the normal in higher-order moments. A departure of this model from Bollerslev's $t$-distributed errors is that we consider a Gram–Charlier type distribution that can take into account skewed and non-mesokurtic (Kendall and Stuart, 1969, p. 86) distributions. Allowing for skewness may be important in modelling interest rates as they are lower bounded by zero and may therefore be skewed.

Studies in the literature typically examine the expectations hypotheses as the null. However, because of the way information variables are specified, many models restrict the set of term structure hypotheses that are commensurate with the model under the alternative. For example, the ARCH-M specification by itself (without a constant) implies that the term premium cannot change sign, thus precluding the preferred habitat and market segmentation hypotheses. On the other hand, the use of the forward premium as an information variable assumes that the term premium, if it is nonzero, may be positive or negative, depending on the sign of the forward premium. Thus, the alternative implicitly excludes the liquidity premium hypothesis. We resolve these difficulties by extending the information variable set using a simple dummy variable technique. In the extended model the sign of the term premium, whether it is constant or possibly changing, is an empirically testable hypothesis.

We construct an augmented ARCH-M model that incorporates the extensions discussed above. This model is consistent with our preliminary findings and the theoretical postulates surveyed earlier. To examine the robustness of the term structure with respect to the specification of the error process, we consider the GARCH model (Bollerslev, 1987) and the linearly declining parameterization of the ARCH model (Engle, 1982). These models are combined with errors that either have a Gram–Charlier type distribution or a $t$-distribution. The empirical results appear to be independent of the structure of the residuals. It is found that there is significant time-varying term premium which may be positive or negative, and the conditional standard deviation has no effect on the mean.

The plan of the rest of the paper is as follows. In Section 2 we define the notations and present some ordinary least-squares results. In Section 3 we describe various versions of extended ARCH-M models. Starting from a general model, we impose restrictions to reduce the model to the simplest version that is congruent with the data. Evidence pro and con the four hypotheses of term structure is discussed. Finally, some concluding remarks are presented in Section 4.

2. NOTATIONS AND PRELIMINARY FINDINGS

We consider 1-month and 2-month interbank rates of the Singapore Asian Dollar Market. The data were collected from (Singapore) Business Times, with monthly observations from 1 October 1976 to 30 March 1987 (in total 127 observations). Denoting the 1-month and 2-month rates by $s_t$ and $S_t$, respectively, we define the implied forward rate, $f_t$, as:

$$f_t = (1 + S_t)/(1 + s_t) - 1,$$

and express all interest rates as annualized figures in percentages.

If $\Phi_t$ is the information set available at time $t$, the term premium is defined as:

$$T_t = f_t - E(s_{t+1} | \Phi_t),$$

where $E(.)$ is the expectation operator. Since expectation is unobservable, direct modelling of $T_t$ is intractable. However, if information is used rationally, this expectation can be replaced
by the future 1-month interest rate. Under this framework the tests conducted are conditional on the rational expectations hypotheses.

Defining $y_t = s_{t+1} - f_t$ as the forecast error, we follow Hansen and Hodrick (1980) to estimate the regression model:

$$y_t = z_t' \beta + u_t,$$

where $z_t$ is the vector of information variables and $\beta$ is the vector of regression parameters. For use as an information variable we have chosen the forward premium $x_t = f_t - s_t$. This variable was also used by Hansen and Hodrick (1980) and Leiderman and Blejer (1987). Indeed, Leiderman and Blejer showed that the forward premium is the most important factor among other variables considered, including the lagged forecast errors.

As noted in the introduction, the use of the forward premium may cause some difficulties. Since the forward premium may take positive or negative values, the expected forecast error may be positive or negative if the regression coefficient is nonzero. Thus, the liquidity premium hypothesis is implicitly ruled out. To get around this problem we define two dummy variables, $d_{1t}$ and $d_{2t}$, by

$$d_{1t} = \begin{cases} 1 & \text{if } x_t > 0 \\ 0 & \text{if } x_t \leq 0 \end{cases}$$

and $d_{2t} = 1 - d_{1t}$, and consider the following regression equation

$$y_t = \beta_0 + \beta_1 x_t d_{1t} + \beta_2 x_t d_{2t} + u_t. \quad (1)$$

This model allows for asymmetric effects of the forward premium. It can be reduced to simpler models by imposing constraints on $\beta_1$ and $\beta_2$. Of special interest are the cases: (i) $\beta_1 = 0$ and $\beta_2 \neq 0$, (ii) $\beta_1 \neq 0$ and $\beta_2 = 0$, (iii) $\beta_1 = \beta_2$ and (iv) $\beta_1 + \beta_2 = 0$. All these constraints can be tested empirically.

Model (1) is estimated using ordinary least-squares, and a number of diagnostic tests are computed. We calculate the Breusch–Pagan test for heteroscedasticity with $(1 x_t d_{1t} x_t d_{2t})'$ as the regressors for the variance. The test statistic is asymptotically a $\chi^2$ with 2 degrees of freedom, and is denoted by BP(2). Ljung-Box tests for serial correlation of the residuals and the squares of the residuals are also computed. They are denoted, respectively, by $Q_1$ and $Q_2$, with degrees of freedom given in parentheses. $Q_2$ is due to McLeod and Li (1983) and was used by Bollerslev (1987) as a test for dependence in conditional second moments. The estimated equation is as follows:

$$y_t = -0.217 - 0.211 x_t d_{1t} - 0.922 x_t d_{2t}$$

$$(-1.554)(-0.948) (-4.816)$$

$BP(2) = 6.537^*$ $\hat{\sigma}^2 = 1.368$

$Q_1(30) = 74.207^*$

$Q_2(29) = 80.597^*$.

1 Case (iii) implies $y_t = \beta_0 + \beta_1 x_t + u_t$, and case (iv) implies $y_t = \beta_0 + \beta_1 \vert x_t \vert + u_t$.

2 The degrees of freedom of $Q_1$ is equal to the number of terms of autocorrelation coefficients minus the number of autoregressive parameters (zero in equation (2)) of the residuals. The degree of freedom of $Q_2$ is equal to the number of terms of autocorrelation coefficients minus the number of parameters of the (conditional) error variance (1 in equation (2)).

3 Figures in parentheses below regression parameter estimates are t-ratios. $\hat{\sigma}^2$ is the variance estimate of the error of the regression equation. Significance of diagnostic checks at 5 per cent level are indicated by asterisks.
Thus, there is significant residual autocorrelation, as well as conditional and unconditional heteroscedasticity. However, it must be pointed out that while the diagnostic tests are asymptotically valid when each type of misspecification is considered on its own, they may not be valid if more than one misspecification exist simultaneously. Motivated by these findings, we shall construct an ARCH model that allows for autocorrelation of the first and second moments of the residuals.

The unconditional measure of sample kurtosis, $\gamma_2$, for the residuals of equation (2) is 4.515. It exceeds the value zero by several asymptotic standard errors. Leptokurtic error structure is clearly evident. As pointed out by Bollerslev (1987), normal errors may not be sufficient to account for observed leptokurtosis. Furthermore, for reasons explained in the introduction the residual errors may be skewed for the type of data we are studying. Thus, we shall extend the ARCH model to permit skewed and leptokurtic errors.

Parameter estimates and their $t$-statistics for $x_t d_{1t}$ and $x_t d_{2t}$ are substantially different. However, formal testing of these parameters based on ordinary least-squares is invalid as the variance estimates are misleading under error misspecification. Such tests will be performed on the extended ARCH-M model.

3. THE EXTENDED ARCH-M MODEL AND EMPIRICAL RESULTS

Consider the error distribution of equation (1). We denote a general family of distributions with mean $\mu_t$ and variance $h_t^2$ by $F(\mu_t, h_t^2)$. Conditional upon information at time $t-1$, we assume $u_t | \Phi_{t-1} \sim F(\mu_t, h_t^2)$. Engle's (1982) ARCH model assumes that $F$ is the normal distribution with mean zero and variance given by a distributed lag equation depending on previous values of $u_t^2$. To allow for skewness and leptokurtosis, we consider a Gram–Charlier type distribution.

We denote $F(0, 1)$ as the standardized distribution with density function given by

$$f(u) = \phi(u) \left(1 + \frac{\lambda_3}{6} H_3(u) + \frac{\lambda_4}{24} H_4(u)\right) = \phi(u) \psi(u),$$

(3)

where $\phi(.)$ is the standard normal density function, and $H_3(.)$ and $H_4(.)$ are the Hermite polynomials defined by

$$H_3(u) = u^3 - 3u$$
$$H_4(u) = u^4 - 6u^2 + 3.$$

The quantities $\lambda_3$ and $\lambda_4$ are, respectively, the standardized measure of skewness and kurtosis. The function $f(u)$ represents the first three terms of the so-called Gram–Charlier series (Kendall and Stuart, 1969, p. 157). A similar density function was suggested by Subrahmaniam (1966) for representing a class of nonnormal distributions. Although $f(u)$ always integrates to 1, it may not always represent a well-defined density function. The problem lies in the possibility of $\psi(u)$ taking negative values. Possible remedies are to redefine $\psi(u)$ or to constraint it to lie in the nonnegative region during the optimization. However, to preserve the straightforward interpretation of $\lambda_3$ and $\lambda_4$ as the skewness and kurtosis parameters, respectively, these remedies are not adopted. Instead, we estimate equation (3) unrestrictedly and select models with a well-defined density function.

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4See Kendall and Stuart (1969, p. 85) for the definition of $\gamma_2$. 
To allow for nonnormal conditional error, Bollerslev (1987) assumed that the conditional error $u_t$ follows a $t$-distribution with mean zero and variance $h_t^2$. Its density function $g(u_t)$ is given by

$$g(u_t) = \Gamma((\nu + 1)/2)\Gamma(\nu/2)^{-1} \left[(\nu - 2)h_t^2\right]^{-1/2} \times \left[1 + u_t^2/(h_t^2(\nu - 2))\right]^{-(\nu + 1)/2-1/2},$$

where $\nu$ is the degree of freedom. We denote the distributions defined by equations (3) and (4) as $e$ and $t$, respectively.

The $e$-distribution has some advantages over the $t$-distribution. Firstly, the $t$-distribution does not permit skewness while the $e$-distribution does. Secondly, while we assume that deviation from normality occurs only in the third and fourth moments, the $t$-distribution assumes that all even moments higher than the fourth order deviate from those of the normal. Indeed, the Gram-Charlier type distribution has the flexibility of modelling nonnormality in moments higher than the fourth order if so desired.

To allow for residual autocorrelation we assume an autoregressive process of order 1, i.e.,

$$u_t | \Phi_{t-1} \sim F(\rho u_{t-1}, h_t^2), |\rho| < 1$$

where $\rho$ is the autoregressive parameter. The conditional variance is assumed to follow the ARCH equation

$$h_t^2 = \omega^2 + \sum_{j=1}^{p} \alpha_j u_{t-j}^2.$$ 

In order to avoid over-parametrization and achieve computational practicability we follow Engle (1982) and Engle, Lilien and Robins (1987) to impose $\alpha_j$ to follow a linearly declining function. Thus, we assume

$$h_t^2 = \omega^2 + \alpha \sum_{j=1}^{p} c_j u_{t-j}^2.$$ 

where

$$c_j = 2(p + 1 - j)/(p(p + 1)).$$

We denote this conditional variance process as the LD model.

To allow the current conditional variance to depend on past conditional variances, we consider the GARCH model. In particular, we consider the GARCH (1, 1) model defined by the equation

$$h_t^2 = \omega^2 + \alpha u_{t-1}^2 + \gamma h_{t-1}^2.$$ 

Finally, to allow the conditional variance to be a determinant of the mean, we extend equation (1) to the ARCH-M formulation

$$y_t = \beta_0 + \beta_1 x_t d_{1t} + \beta_2 x_t d_{2t} + \delta h_t + u_t \quad t = 1, \ldots, T.$$ 

Equations (1) and (3) through (8) complete the specifications of various versions of the extended ARCH-M model. Conditional on the initial values of the data, the log-likelihood function can be written as

$$L(\theta) = \sum_{t=1}^{T} L_t(\theta),$$

---

5 Generalization of the autoregressive process to higher order is obvious.
where \( \theta \) is the vector of all parameters of the model. For the \( e \)-distributed errors, \( L_t(\theta) \) is given by
\[
L_t(\theta) = -\log(h_t) - \frac{\varepsilon_t^2}{2} + \log \psi(\varepsilon_t)
\]
where \( \varepsilon_t = (u_t - \rho u_{t-1})/h_t \), and the irrelevant constant has been dropped. Similarly, for the \( t \)-distributed errors, \( L_t(\theta) \) is given by
\[
L_t(\theta) = \log(g(\varepsilon_t))
\]
where \( \varepsilon_t = u_t - \rho u_{t-1} \).

Estimates of \( \theta \) can be obtained by maximizing \( L(\theta) \) with respect to \( \theta \). Presample values of \( u_t \) are set to their expected values zero and presample values of \( u_t^2 \) in equations (6) and (7) are set to the ordinary least-squares estimates of the residual variance of equation (1). Estimates calculated in this paper are obtained using the IMSL FORTRAN subroutine ZXMIN for optimizing a function by a quasi-Newton method.

The following diagnostic checks are considered in each model. We calculate the Ljung-Box tests \( Q_1 \) and \( Q_2 \). These tests are based on the standardized residuals \( \hat{\varepsilon}_t = (\hat{u}_t - \hat{\rho} \hat{u}_{t-1})/\hat{h}_t \) and \( \hat{\varepsilon}^2_t \), where quantities with 'hats' denote maximum-likelihood estimates. Tests for structural change are constructed using the Lagrange multiplier (LM) principle. We augment the main equation (8) by \( q \) regressor vectors, each of which is a column of zeros except the \( i \)th element, which is one. We let \( i = n - q + 1, \ldots, n \), i.e. the augmented vectors represent mean shifts in the last \( q \) observations. We test the null hypothesis that the coefficients of these vectors are zero. LM test for this hypothesis can be calculated using the procedure described by Engle, Lilien, and Robins (1987). An advantage of the LM test is that the model need not be re-estimated. We denote this test statistic by \( S(q) \), which is asymptotically distributed as \( \chi^2_q \).

The extended LD version of ARCH-M model is estimated conditional on \( p \), which is varied between 6 and 12. We select the model with the maximum likelihood. As the models are nonnested for different values of \( p \) the likelihood ratio principle for selecting \( p \) does not apply. However, the results are quite robust with respect to \( p \). The maximum likelihood is a concave function of \( p \) over the range of values considered, and the parameter estimates and \( t \)-ratios are very stable.

Table I summarizes the estimation results of the general unrestricted models of equations (1) and (3) through (8), incorporating ARCH-M and autocorrelated residuals. The estimates are quite stable with respect to different error specifications.

Residual nonnormality is detected through the \( e \)-distribution, as demonstrated by the significant excess kurtosis. It can be checked that the estimates of skewness and kurtosis give rise to well-defined density functions. Although the reciprocal of the degrees of freedom of the \( t \)-distribution is statistically insignificant, the estimated values of \( \nu \) (approximately 7 to 8) are not large enough to warrant the normal approximation. The coefficient of the conditional standard deviation (\( \hat{\delta} \)), the autoregressive parameter (\( \hat{\rho} \)) and the skewness coefficient (\( \hat{\lambda}_3 \)) are insignificant at 5 per cent level for all equations. Thus, we drop these parameters one at a time.
### Table I. Estimated term structure equations: general unrestricted models

<table>
<thead>
<tr>
<th>Model</th>
<th>$\beta_0$</th>
<th>$\beta_1$</th>
<th>$\beta_2$</th>
<th>$\delta$</th>
<th>$\rho$</th>
<th>$\omega$</th>
<th>$\alpha(p)$</th>
<th>$\gamma$</th>
<th>$1/\nu$</th>
<th>$\lambda_3$</th>
<th>$\lambda_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LD, $e$</td>
<td>0.103</td>
<td>-0.427</td>
<td>-0.488</td>
<td>-0.248</td>
<td>0.139</td>
<td>0.359</td>
<td>0.897(8)</td>
<td>-0.127</td>
<td>1.685</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.687)</td>
<td>(-2.672)</td>
<td>(-2.580)</td>
<td>(-1.557)</td>
<td>(1.534)</td>
<td>(2.880)</td>
<td>(3.745)</td>
<td>(0.406)</td>
<td>(2.232)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LD, $t$</td>
<td>0.177</td>
<td>-0.426</td>
<td>-0.628</td>
<td>-0.383</td>
<td>0.086</td>
<td>0.312</td>
<td>0.948(8)</td>
<td>0.126</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.255)</td>
<td>(-2.699)</td>
<td>(-3.511)</td>
<td>(-1.681)</td>
<td>(0.876)</td>
<td>(2.773)</td>
<td>(3.930)</td>
<td>(1.002)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GARCH, $e$</td>
<td>0.068</td>
<td>-0.359</td>
<td>-0.406</td>
<td>-0.187</td>
<td>0.170</td>
<td>0.228</td>
<td>0.404</td>
<td>0.613</td>
<td>-0.105</td>
<td>2.431</td>
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<tr>
<td></td>
<td>(0.474)</td>
<td>(-2.267)</td>
<td>(-2.127)</td>
<td>(-0.828)</td>
<td>(1.839)</td>
<td>(2.697)</td>
<td>(2.038)</td>
<td>(5.783)</td>
<td>(0.301)</td>
<td>(3.246)</td>
<td></td>
</tr>
<tr>
<td>GARCH, $t$</td>
<td>0.115</td>
<td>-0.490</td>
<td>-0.784</td>
<td>-0.282</td>
<td>0.023</td>
<td>0.171</td>
<td>0.473</td>
<td>0.594</td>
<td>0.143</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.918)</td>
<td>(-3.074)</td>
<td>(-4.638)</td>
<td>(-1.271)</td>
<td>(0.204)</td>
<td>(1.869)</td>
<td>(1.940)</td>
<td>(5.139)</td>
<td>(1.060)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*LD is the linearly declining weight model (equation (6)), GARCH is the generalized autoregressive conditional heteroscedastic model (equation (7)), $e$ is the error distribution defined in equation (3) and $t$ is the Student's $t$-distribution with $\nu$ degree of freedom, as defined in equation (4). Figures in parentheses are $t$-ratios. For LD models the figure in the parentheses following $\alpha$ is the number of lagged terms $p$ defined in equation (6).*

### Table II. Estimated term structure equations: reduced models

<table>
<thead>
<tr>
<th>Model</th>
<th>$\beta_0$</th>
<th>$\beta_1 = \beta_2$</th>
<th>$\omega$</th>
<th>$\alpha$</th>
<th>$\gamma$</th>
<th>$1/\nu$</th>
<th>$\lambda_3$</th>
<th>$\lambda_4$</th>
<th>$Q_1$</th>
<th>$Q_2$</th>
<th>$S$</th>
<th>LR</th>
</tr>
</thead>
<tbody>
<tr>
<td>LD, $e$</td>
<td>-0.015</td>
<td>-0.564</td>
<td>0.360</td>
<td>0.920(8)</td>
<td>1.720</td>
<td>30.057</td>
<td>36.423</td>
<td>12.030</td>
<td>0.154</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.290)</td>
<td>(-5.784)</td>
<td>(2.968)</td>
<td>(3.778)</td>
<td>(2.439)</td>
<td>(30)</td>
<td>(28)</td>
<td>(12)</td>
<td>(1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LD, $t$</td>
<td>-0.006</td>
<td>-0.582</td>
<td>0.327</td>
<td>1.004(8)</td>
<td>0.184</td>
<td>29.139</td>
<td>35.357</td>
<td>12.123</td>
<td>0.248</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.107)</td>
<td>(-5.874)</td>
<td>(2.604)</td>
<td>(3.619)</td>
<td>(1.475)</td>
<td>(30)</td>
<td>(28)</td>
<td>(12)</td>
<td>(1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GARCH, $e$</td>
<td>-0.014</td>
<td>-0.546</td>
<td>0.207</td>
<td>0.376</td>
<td>0.639</td>
<td>1.877</td>
<td>30.397</td>
<td>39.223</td>
<td>12.030</td>
<td>0.140</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.263)</td>
<td>(-5.080)</td>
<td>(2.276)</td>
<td>(1.934)</td>
<td>(6.038)</td>
<td>(2.399)</td>
<td>(30)</td>
<td>(27)</td>
<td>(12)</td>
<td>(1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GARCH, $t$</td>
<td>0.001</td>
<td>-0.649</td>
<td>0.185</td>
<td>0.517</td>
<td>0.577</td>
<td>0.187</td>
<td>27.509</td>
<td>39.887</td>
<td>12.174</td>
<td>0.511</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.017)</td>
<td>(-6.293)</td>
<td>(1.886)</td>
<td>(2.036)</td>
<td>(5.191)</td>
<td>(1.432)</td>
<td>(30)</td>
<td>(27)</td>
<td>(12)</td>
<td>(1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*See note (a) of Table I. Only significant parameters in Table I are re-estimated. The models impose the constraint $\beta_1 = \beta_2$. $Q_1$ is the portmanteau test for residual serial correlation. $Q_2$ is the portmanteau test for serial correlation in the squares of the residuals. $S$ is the Lagrange multiplier test for model stability. LR is the likelihood ratio test for the constraint $\beta_1 = \beta_2$. All test statistics are distributed asymptotically as $\chi^2$. Figures in parentheses are the degrees of freedom.
time and re-estimate the models. Starting from higher-order moments, we first drop $\lambda_3$, followed by $\rho$ and then $\delta$. The coefficients of the positive and negative forward premiums in the reduced equations are very similar. The $t$-statistics of testing for symmetric forward premium effects (i.e. $\beta_1 = \beta_2$) are insignificant. Thus, we further restrict $\beta_1 = \beta_2$ in the final equations. The results are summarized in Table II.

It can be seen that the diagnostic statistics $Q_1$, $Q_2$ and $S$ are insignificant at 5 per cent level for all equations, indicating that the misspecification problems of equation (2) have been resolved. There is evidence for ARCH and GARCH in the residuals, as well as conditional nonnormality. The estimates of the kurtosis yield well-defined density functions. All constant intercepts are insignificant and their values are similar and small. The coefficients of the forward premium are significant and vary within the narrow range of $-0.546$ to $-0.649$. Thus, there is a close agreement in the term structure among various error specifications. All models indicate that the conditional standard deviation is insignificant, and there is approximately 0.6 percentage point increase (decrease) in the term premium per 1 percentage point increase (decrease) in the forward premium. This evidence is against the expectations hypothesis and the liquidity premium hypothesis. The existence of a time varying term premium favours the preferred habitat hypothesis and the market segmentation hypothesis.

4. CONCLUSION

We have considered extended ARCH-M models to allow for residual autocorrelation and deviation from normality in higher-order moments. To permit asymmetric effects of the forward premium on the term premium, we use a simple dummy variable technique. The general model is estimated and simplified to a version that is compatible with the data. This approach is applied to a data set of US dollar interbank deposit rates in the Asian Dollar Market of Singapore.

In contrast to Engle, Lilien, and Robins (1987) we find that conditional standard deviation has insignificant effect on the term premium. The preferred model is an ARCH/GARCH process with leptokurtic and serially uncorrelated disturbances. It is found that the forward premium has significant symmetric effects on the term premium. The result is in favour of the preferred habitat hypothesis and the market segmentation hypothesis of the term structure of interest rates.

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REFERENCES


9 Dropping the parameters sequentially provides a stability check for the estimates.


