# Arbetsrapport

Nr 14

Februari 1994

# An Analysis of Time Varying Risk Premia of Swedish T-bills

*Peter Hördahl*

---

The main part of this paper was done while I was visiting the Riksbank as a summer employee. Their help and hospitality is gratefully acknowledged. I would like to thank the Research group at the Riksbank, Michael Bergman, Magnus Dahlquist, David Edgerton, Björn Hansson, Pekka Hietala, Lars Nordén and seminar participants at the Riksbank, the NDPD Workshop on Asset Pricing in Helsinki, and the Universty of Lund for helpful comments and suggestions.

ISSN 1101-6604
ISRN SVRB-AR--14--SE

# AN ANALYSIS OF TIME VARYING RISK PREMIA OF SWEDISH T-BILLS

Peter Hördahl

February 1994

## Abstract

In this study the excess holding yield earned from holding a long term t-bill or bond and borrowing at a short rate is investigated for Swedish data. The purpose is to investigate whether there is any evidence of time variation in the excess holding yield and, if so, whether it is possible to model it as a risk premium dependent on its variability. The model used is Engle, Lilien and Robins (1987) ARCH-M model, which postulates that the excess holding yield is a function of the conditional variance, which in turn is assumed to follow an ARCH process.

Four sets of interest rates are examined, 60 vs 30 day bills, 120 vs 60 day bills, 180 vs 90 day bills, and 10 year bonds vs 30 day bills. The standard ARCH test presented in Engle (1982) is used to investigate whether any ARCH effects are present. No evidence of ARCH is found in the 60/30 day or 10 year/30 day sets. Some indications of ARCH is present in the 180/90 day set, and more strongly in the 120/60 day data set.

Based on the results of these tests, the two latter sets of excess holding yields are modelled as ARCH-M. The model is unsuccessful for the 180/90 day excess return since there is no support for the hypothesis that the excess holding yield is dependent on the conditional variance. There are, however, some indications of ARCH-effects present in the material. As for the 120/60 day excess holding yield, this is successfully modelled as ARCH-M. The presence of a time varying premium in this particular return series suggests the preferred habitat hypothesis, while the results from the three other series indicate that the expectations hypothesis is to be preferred.

Considering the combined results from the four excess return series lead to the conclusion that a general variance-dependent risk premium is unlikely to be present in the Swedish market for treasury bills and bonds. Furthermore, the evidence in favour of a general time varying term premia is quite weak. Therefore, the conclusion is that the expectations hypothesis cannot be rejected for the data examined, with the exception of 120/60 day t-bills.

# Contents

# 1 Introduction

Many empirical studies in the area of macroeconomics and finance have been related to the term structure of interest rates. This is a topic of interest to both dealers in the market who try to take advantage of possible arbitrage opportunities, and to the monetary authorities who seek indicators of the monetary condition in order to shape policy.

From the viewpoint of financial economics, the idea that there exists a trade-off between the risk of holding a certain asset and the expected return of that asset is central. It is therefore a natural assumption that this relationship should hold also in the fixed income market. More specifically, the excess return received from buying a long term t-bill and borrowing at the short rate should be positively related to the risk of such a strategy. Assuming that this risk is not constant, the expected return should be higher in times when uncertainty is greater.

The statement that the risk of such a strategy is not constant can be interpreted as saying that the variance of the excess holding yield varies over time, if risk is measured by volatility. The first task is therefore to establish whether any such time variation is indeed present. If this is the case, the hypothesis that the excess return is a premium received in times of "high risk" may be tested. This will be done using the methods of Engle, Lilien and Robins (1987), who model the excess return as a time varying risk premium in the ARCH (autoregressive conditional heteroskedasticity) framework. Using American data for the period 1960 to 1984, they find a positive and significant relationship between the excess return and the risk. Other similar studies include Lee and Tse (1991), who also find a time varying term premium, but no evidence of the relationship risk - expected return, for data from the Singapore Asian US Dollar market 1976-1987.

Tests are carried out for four sets of Swedish excess holding yield data, namely 60 vs 30, 120 vs 60, and 180 vs 90 day t-bills, and also for 10 year treasury bonds vs 30 day bills. The paper is organized as follows. Section 2 gives a short description of the theoretical model outlined by Engle *et al* (1987) for the relationship between risk and return, and a brief recapitulation of the basic hypotheses of the term structure. In section 3 the models used for the empirical tests are presented. The results of the tests for time-variation are found in section 4, while sections 5 and 6 contains the results of the attempts to model the excess holding yield as a risk premium for 120 vs 60 day bills, and 180 vs 90 day bills respectively. Finally, section 7 summarizes the results.

# 2 Theoretical Models

A central thought in the area of finance is that investors are risk averse and therefore require compensation in the form of higher expected return as the risk of holding an asset increases. This idea is incorporated in a basic risk-return model outlined by Engle, Lilien and Robins (1987), which constitutes the basis for the econometric model proposed in their paper. According to this theoretical model, the economy is assumed to consist of a risky asset and a riskfree asset, and investors are assumed to exhibit constant absolute risk aversion. Given these assumptions, an expression is derived for the expected excess holding yield of the risky asset over the risk-free, which states that excess return should increase as the variance of the return increases.[1]

In this case, risk is measured by the variance or standard deviation of the excess return. A useful extension of the model would be to specify the excess return to be dependent on market risk, as opposed to return variance, as in Bollerslev, Engle and Wooldridge (1988) or Engle, Ng and Rothschild (1990). It is also possible that the excess holding yield depends on other explanatory variables, and not at all on volatility. It is, however, the validity of the relationship proposed by Engle *et al* (1987) which will be tested empirically for Swedish money market data in this study.

As mentioned earlier, the data to be modelled is the excess holding yield of a long term t-bill or bond over a short term bill, which suggests that the data also may be analysed in the context of term-structure theories. The excess holding yield is simply the realized term premium, apart from a random expectations error. According to different theories, this term premium may be positive, negative or zero.[2] The expectations hypothesis stipulates that the term premium is constant or even zero, as in the pure expectations theory. Consequently, this contradicts the set-up of the model described above which implies a time varying term premium.

The liquidity premium hypothesis requires the term premium to be positive. According to this theory, investors have short investment horizons and therefore require a positive premium to hold long term bills. The preferred habitat hypothesis stipulates that the term premium may be positive or negative, depending on the preferences of investors regarding the investment horizon. A related theory is the market segmentation hypothesis which also assumes that investors have different investment horizons. According to this theory, however, the different maturity sectors are unrelated in the sense that

---

1 See Engle, Lilien and Robins (1987), p 392-394 for details.

2 Throughout the paper, the designation "excess holding yield" will be used as synonymous with "term premium". See for example Shiller (1990) for a discussion of the exact definitions.

investors and borrowers are unwilling to change their investment horizon, regardless of any term premium.

A substantial amount of research has been carried out in the field of term structure theories. Most studies performed on US and UK data result in the rejection of the expectations model; see Shiller (1990) for a survey of empirical work. A few studies have been carried out on Swedish data. Hörngren (1986) uses quotations from the short term end of the Swedish bank certificate market during 1980-1985, and finds that information about future interest rates to some extent is present in forward rates. Information about future excess returns is also found in the forward rates, leading to the rejection of the pure expectations theory. Bergman (1988) finds evidence of nonzero risk premia in the market for Swedish t-bills during the period 1985-1986, and also indications that the term premia is time varying. The pure expectations hypothesis is thus rejected also in Bergman's study. Ekdahl & Warne (1990), on the other hand, using 5 year bonds and 30 day treasury bills during 1983-1988 are not able to reject a rational expectations model of the term structure. Furthermore, Dahlquist & Jonsson (1993) find that the joint hypothesis of rational expectations and a zero term premium cannot be rejected, using Swedish t-bill data with maturities between one and twelve months during the period 1984-1992.

# 3 Empirical Models

An often observed phenomena in economic time series, and especially in financial series, is that there is a tendency of volatility clustering, meaning that high volatility tends to be followed by high volatility and analogous for low volatility. One frequently used model for time series with this sort of time-dependent variance is Engle's (1982) ARCH model, which models the conditional variance as a linear function of past squared errors:

$$y_t = \mathbf{x}_t\beta + \varepsilon_t \qquad V[\varepsilon_t|\Psi_{t-1}] = h_t^2$$
$$h_t^2 = \gamma + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 \tag{1}$$

Here, $\mathbf{x}_t$ is a vector of explanatory variables and $\Psi_{t-1}$ is all available information at time $t$-1.

A possible extension of the model is to allow not only lagged squared errors but also past conditional variances to affect the current conditional variance as in Bollerslev's (1986) generalized ARCH (GARCH) model:

$$h_t^2 = \gamma + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \omega_i h_{t-j}^2 \tag{2}$$

This extension is useful in cases where many ARCH parameters are called for, since a GARCH model with only a few parameters often perform as well as, or even better than, an ARCH model with a long lag length. This is analogous to the use of an ARMA model instead of an MA specification in ordinary time series modelling.

The set-up of model [1] does not, however, capture the main idea of the model discussed in the previous section that not only the variance is conditional on past squared errors, but that also the mean should be dependent on past squared errors. To allow for this possibility, Engle, Lilien and Robins (1987) introduced the so called ARCH in mean (ARCH-M) model:

$$y_t = \mathbf{x}_t'\beta + \delta h_t + \varepsilon_t$$
$$h_t^2 = \gamma + \alpha \sum_{i=1}^{q} w_i \varepsilon_{t-i}^2 \tag{3}$$

Here, the mean is determined by the conditional standard deviation, possibly in addition to other explanatory variables. The choice of including the standard deviation instead of the variance reflects an assumption that the impact on the dependent variable is less than proportional to a change in variance. This assumption is incorporated in the theoretical model outlined by Engle *et al* (1987). However, it is possible that other measures of return variability are better to use, such as the conditional variance or the log of the conditional standard deviation.

The specification of the conditional variance in [3] is modified compared to the usual set-up of ARCH models (as in model [1]), to avoid the necessity of estimating an excessive amount of parameters. Instead of having one ARCH-parameter for every lagged squared residual plus the intercept, a weighted average of previous squared residuals is formed, and only two ARCH parameters are estimated. The weighting is designed as a linearly declining model, thereby giving the observations closest in time the largest weights and thus greater importance as information variables. Another reason for this construction of the conditional variance function is that estimation of one parameter for every lagged squared residual in an ARCH-M model makes convergence difficult to achieve and sometimes results in negative ARCH parameters.

The time series to be modelled in this study is the excess holding yield on a long term bill or bond relative to a short term bill. Following Engle *et al* (1987), the excess holding yield is hypothesized to consist of a time-varying risk premium and a stochastic error term:

$$y_t = \mu_t + \varepsilon_t \qquad [4]$$

Conditional on the assumption that the expected excess return should depend only on the variance of the return, the expected excess holding yield can be expressed in the following way:

$$E[y_t] = \beta + \delta h_t \qquad [5]$$

where $h_t$ is specified as in the second equation of [3].

Naturally, model [4] can be augmented with other factors thought to be relevant as explanatory variables for the risk premium. Various conceivable factors which have been suggested in the literature include lagged excess holding yield, the present short term interest rate, the long term rate, and the difference between the long and short rates. Other variables which may be relevant for a small open economy with fixed exchange rate are foreign interest rates and foreign exchange rates.

There are a number of statements which can be made about model [3] in terms of the various theories of the term structure discussed in the previous section. If the excess holding yield is not constant, so that one or more of the independent variables in the first equation of [3] are significant, then the expectations theory is excluded. Such a time varying term premium would suggest the preferred habitat theory, or possibly the liquidity premium hypothesis if the premium is positive at all times. If the specification of the model allows the term premium to change sign, then also the liquidity premium hypothesis is ruled out. If there is no term premium at all, constant or time varying, then this would suggest the pure expectations theory.

In the data series where evidence of ARCH effects are found, model [3] and all of the above mentioned extensions are tested in an attempt to find the model which fits the data of the excess holding yield most adequately. This is done in the two sections following the next, in which tests for ARCH are carried out.

# 4 Preliminary Tests

## 4.1 Data

The data used in this study consists of the following series of interest rates: 30, 60, 90, 120, and 180 day Swedish treasury bills (Statsskuldväxel), and 10 year Swedish treasury bonds. All data is obtained from the Swedish central bank's (Riksbanken) database. The sample period is March 1984 (January 1987 in the case of the 10 year bonds) to July 1992, which is shortly before Sweden was forced to give up its policy of fixed exchange rate. The original interest rate series consist of daily observations of closing bid and ask rates. From this data, observations for the 15:th of each month is selected, or as near as possible to this date if no data is available for the 15:th. The reason for selecting observations from this particular date is that Swedish treasury bills are issued in the middle of the month and therefore mature at that time of the month. Thus, selecting the 15:th as the date of observation should mean that the reported maturity of the bills are as close as possible to the actual maturity. Finally, the average of the bid and ask rates is calculated for each selected observation.

In addition to the Swedish interest rate series, data on the German short term interest rate (90 day Eurorate) and the rate of exchange between the Swedish Krona and the theoretical ECU is collected for the period of interest. Also this data is obtained from the Riksbank.

## 4.2 The Excess Holding Yield

The ex-post excess holding yield of a t-bill with $D$ days to maturity over a bill with $d$ days remaining, where $D = 2d$, is defined as

$$y_t = \frac{(1+R_t)^2}{(1+r_{t+1})} - (1+r_t) \qquad [6]$$

where $r_t$ and $R_t$ represent the rates of return of the short and the long term bills respectively. The rates are expressed as rates of return per $d$ days. In other words, if we have 30 and 60 day bills, then $r_t$ and $R_t$ would be expressed as monthly rates of return. In order to avoid an overlapping data problem, the period between observations is set equal to the maturity of the short bill ($d$). Thus, in the 30/60 day case, monthly observations are used, whereas quarterly observations are used in the case of 90/180 day bills.

The definition in [6] implies that the short term bill is considered the less risky of the two, since positive excess holding yield is obtained as compensation for the risk taken when for example a 60 day bill is bought and held for one month, and this is financed by borrowing at the 30 day rate. This in turn implies the liquidity premium theory or possibly the preferred habitat theory if the excess holding yield is not constant. Negative excess holding yield, on the other hand, suggests that there are more investors who prefer long term to short term bills, i e the preferred habitat theory (or segmented market hypothesis).

The formula in [6] is suitable for calculating the excess holding yield between two relatively short termed bills. However, if one is interested in the excess holding yield between a 10 year bond and a 30 day bill, then another method must be used to estimate this. Following Engle *et al* (1987), the bond is assumed to be of infinite horizon relative to the 30 day bill. This allows the monthly excess holding yield to be approximated as:

$$y_t = R_t - r_t + \frac{R_t}{R_{t+1}} - 1 \qquad [7]$$

where $R_t$ is the monthly yield to maturity of the bond, and $r_t$ is the 30 day treasury bill rate.[3]

Summary statistics for the excess holding yield in the four cases considered are presented in table 1 page 13.

Figures 1-4 in appendix 1 show the excess holding yield during the period of investigation. It is apparent from the figures that the excess return is quite irregular and in most cases rather small. From table 1, one can also confirm that in only one case is the mean of the excess holding yield statistically different from zero at the 5% level, namely in the 180 vs 90 day case. The unconditional mean is -0.082% per quarter (about -0.33% per annum), which indicates the presence of negative excess holding yield between six month and three month Swedish treasury bills. The average annual yield on the 180 day bill was 11.97% during the observed period, compared to 12.06% for the 90 day instrument, suggesting that investors in general prefer the longer debt instrument to the shorter. These preliminary results are quite different to

---

3 Quotations for coupon bonds on the Swedish market are in the form of annual yields to maturity. This is calculated in the usual fashion: $P = B(1+R)^{-T} + \sum_{i=1}^{T} C_i(1+R)^{-i}$, where $P$ is the price of the $T$-year bond, $B$ is the face value, $C_i$ is the coupon at time $i$, and $R$ is the resulting yield to maturity. This is admittedly only an approximation, since the yield to maturity is not the true certain yield of the bond during its remaining life, unless the relevant zero-coupon rates are identical on all future coupon payment days. The yield to maturity is, however, commonly used as an approximation for the true yield, among others by Engle *et al*.

*Table 1. Summary statistics / excess holding yield*

| | Mean | St.dev. | Skewness | Kurtosis | Rate of return reported |
|---|---|---|---|---|---|
| 60 vs 30 days | -0.010<br>(-1.433) | 0.071 | -1.518 | 7.542 | monthly |
| 120 vs 60 days | -0.003<br>(-0.252) | 0.095 | 0.276 | 8.045 | 60-day |
| 180 vs 90 days | -0.082<br>(-2.051) | 0.230 | -0.724 | 3.557 | quarterly |
| 10 yrs vs 30 days | 0.293<br>(0.872) | 2.734 | -0.238 | 4.787 | monthly |

The reported figures are in percent per time interval given in the last column. Figures in parenthesis denote t-ratios for testing the null hypothesis that Mean = 0.

the findings of Engle, Lilien and Robins (1987) for American data, who estimated the average excess holding yield on 180 day vs 90 day t-bills to 0.568% p a during the period 1960 to 1984.

It is also noteworthy that although the average excess holding yield in the case of 10 year bonds vs 30 day bills is positive and quite large (around 3.5% p a), it is not statistically different from zero at the 10% level. This is due to the large variability, as can be seen in figure 4, appendix 1. Also in this case the results given here differ from those presented by Engle *et al* (1987). Their estimate of the average excess holding yield on a long bond (20 year AAA corporate bond) over a short term bill (3 month t-bill) is about -3% per annum, for the period 1953 to 1980.

## 4.3 Tests for ARCH

In order to investigate whether any ARCH effects are present in the material, the standard ARCH test proposed by Engle (1982) is carried out. This involves the following OLS estimations:

$$y_t = \beta + \varepsilon_t$$
$$\varepsilon_t^2 = \gamma + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 \qquad [8]$$

The results from the second regression can be used as a Lagrange Multiplier test for $\alpha_1 = \ldots = \alpha_q = 0$. The appropriate test statistic of this LM test is

$T \cdot R^2$, where $T$ denotes the sample size, and the test statistic is asymptotically distributed as $\chi_q^2$ if no ARCH effects are present. Another way to test for ARCH effects is to use standard time series tests for autocorrelation in the squared residuals, such as the Ljung Box test ($Q_2$).[4] The results of these tests are given in table 2 for the different sets of excess holding yields examined. The standard Ljung Box test statistic for residual autocorrelation is also presented ($Q_1$).

The results in table 2 clearly rejects the possibility of ARCH being present in the excess holding yield of 60 vs 30 day bills and 10 year bonds vs 30 day bills, where none of the test statistics are significant. As for the other two return series, the results are less clear-cut. In both the 120 vs 60 and the 180 vs 90 day cases, three out of five test statistics are significant at the 5% level. Consequently, it cannot be ruled out that ARCH effects are indeed present in these two series. In the following sections these two excess holding yield series will therefore be modelled as riskpremia in the ARCH-M framework.

*Table 2. Test statistics for ARCH and autocorrelation*

| Excess holding yield: | 60 vs 30 days | | 120 vs 60 days | | 180 vs 90 days | | 10 y vs 30 days | |
|---|---|---|---|---|---|---|---|---|
| ARCH-tests: $TR^2$ [df] | 0.457<br>(0.499) | [1] | 0.112<br>(0.738) | [1] | 6.193<br>(0.013) | [1] | 0.578<br>(0.447) | [1] |
| | 3.401<br>(0.757) | [6] | 21.876<br>(0.001) | [6] | 6.110<br>(0.191) | [4] | 6.549<br>(0.365) | [6] |
| | 6.854<br>(0.867) | [12] | 26.440<br>(0.009) | [12] | 6.262<br>(0.618) | [8] | 8.712<br>(0.727) | [12] |
| Ljung-Box: $Q_2$ [df]<br>(squared residuals) | 4.694<br>(0.454) | [6] | 13.241<br>(0.021) | [6] | 8.805<br>(0.032) | [4] | 4.533<br>(0.431) | [6] |
| | 6.524<br>(0.836) | [12] | 13.527<br>(0.260) | [12] | 46.694<br>(0.000) | [8] | 10.011<br>(0.529) | [12] |
| Ljung-Box: $Q_1$ [df] | 17.673<br>(0.126) | [12] | 17.898<br>(0.119) | [12] | 6.260<br>(0.618) | [8] | 22.727<br>(0.030) | [12] |

Figures in brackets denote degrees of freedom for the various test statistics. Figures in parenthesis are probability values for the null hypotheses of no ARCH effects and no residual autocorrelation respectively.

4 See Bollerslev (1987) for details.

# 5 Empirical Results for 120 vs 60 Day T-bills

## 5.1 The Ordinary ARCH-M Model

Motivated by the test results above, the parameters of the ARCH-M model are estimated with a number of different lags in the weighted average of squared residuals. The most common method utilized is the maximum likelihood method, which is employed in this paper as well. The likelihood function can be written as

$$L(\phi)=\prod_{t=1}^{T}L_t(\phi), \qquad L_t(\phi)=\frac{1}{h_t\sqrt{2\pi}}\cdot\exp\left(-\frac{\varepsilon_t^2}{2h_t^2}\right).$$

conditional on $\varepsilon_t|\varepsilon_{t-1}\sim N(0,h_t^2)$. The symbol $\phi$ denotes the vector of parameters in the model. The log likelihood function may therefore be expressed as follows, omitting irrelevant constants:

$$\ln L(\phi)=\sum_{t=1}^{T}\ln L_t(\phi), \qquad \ln L_t(\phi)=-\ln(h_t)-\frac{\varepsilon_t^2}{2h_t^2} \qquad [9]$$

This expression is maximized with respect to $\phi$ using the BHHH-algorithm, and the resulting parameters are the maximum likelihood estimates.[5]

Applying this to the data at hand and letting the lagged squared residuals included in the conditional variance equation vary from one to twelve, gives the following parameter estimates for the model with the highest likelihood value:

$$y_t=\underset{(-1.58)}{-0.037}+\underset{(1.43)}{0.431}h_t+\varepsilon_t$$

$$h_t^2=\underset{(0.81)}{0.001}+\underset{(2.82)}{1.512}\sum_{i=1}^{7}w_i\varepsilon_{t-i}^2, \qquad w_i=(8-i)/28 \qquad [10]$$

$$\ln L=97.16$$

Figures in parenthesis denote $t$-ratios.

---

5 See Berndt, Hall, Hall, Hausman (1974) for details. The actual estimation was carried out with the Maxlik-routine in GAUSS.

A useful property of ordinary ARCH models is that the information matrix is block diagonal between the parameters of the conditional mean and the parameters of the conditional variance. This enables the estimation of the parameters in the respective equations of the mean and the variance to be carried out separately. In the ARCH-M model however, the information matrix is no longer block diagonal, and estimation of all parameters must be performed simultaneously. Furthermore, this makes the model sensitive to misspecifications, since correct specification of the entire model is required in order to obtain unbiased and consistent estimates. This point is emphasized in a number of papers covering this model; see Engle *et al* (1987), Bollerslev, Chou and Kroner (1992) and Kroner & Lastrapes (1993).

With this in mind, different tests for misspecification are carried out. One important diagnostic test concerns the assumption of normally distributed errors, which is a prerequisite for utilizing [9] in the maximum likelihood estimation. The validity of this assumption may be tested by taking a look at the third and fourth moments of the residuals:

$$\sqrt{b_1} = \tilde{\sigma}^{-3} \frac{1}{T} \sum_{t=1}^{T} \varepsilon_t^3$$

$$b_2 = \tilde{\sigma}^{-4} \frac{1}{T} \sum_{t=1}^{T} \varepsilon_t^4 \qquad [11]$$

where $\tilde{\sigma}^2$ denotes the ML estimator $\tilde{\sigma}^2 = \varepsilon' \varepsilon / T$. These are the measures of skewness and kurtosis and should have the following asymptotic distribution if the tested residuals are normal:

$$\sqrt{b_1} \overset{A}{\sim} N(0, 6/T)$$

$$b_2 \overset{A}{\sim} N(3, 24/T).$$

A test for non-normality may be based on the following Wald statistic by Bera and Jarque, which is asymptotically distributed as $\chi_2^2$:

$$N = (T/6)b_1 + (T/24)(b_2 - 3)^2. \qquad [12]$$

The standardized residuals of [10] give a measure of skewness and kurtosis of -1.502 and 6.221 respectively which results in a test statistic of 40.42, thus clearly indicating non-normality.

With this result in mind, the normal distribution is replaced with a distribution which takes into account excess skewness and kurtosis for the maximum likelihood estimation. Following the suggestions of Lee and Tse (1991), a so called Gram-Charlier type distribution is used, with the standardized distribution $G(0,1)$ given by the following density function

$$g(\varepsilon) = f(\varepsilon)\,\psi(\varepsilon), \\ \psi(\varepsilon) = \left(1 + \frac{\lambda_3}{6} H_3(\varepsilon) + \frac{\lambda_4}{24} H_4(\varepsilon)\right) \qquad [13]$$

where $f(\cdot)$ is the standard normal density function. The parameters $\lambda_3$ and $\lambda_4$ are the maximum likelihood estimates of the standardized measures of skewness and kurtosis, and the so called Tchebycheff-Hermite polynomials $H_r(\cdot)$ are given by

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

Generalization to take into account deviation from normality of higher moments is possible by adding more terms to the three in the Gram-Charlier series above; see Kendall & Stuart (1958). Since $\lambda_3$ and $\lambda_4$ are estimated along with the other parameters of the ARCH-M model, the possibility exists that $\psi(\varepsilon)$ and therefore $g(\varepsilon)$ takes a negative value. To avoid this, $\psi(\varepsilon)$ may be forced to take a non negative value during the estimation process by simply taking the absolute value. However, by utilizing this method, $\lambda_3$ and $\lambda_4$ lose their interpretations as measures of excess skewness and kurtosis, and the resulting distribution may differ from the one intended, thereby making the maximum likelihood function invalid. Therefore, a penalty function is used to ensure that these parameters result in well behaved values of $\psi(\varepsilon)$ and of the distribution function.

Another assumption which is important when dealing with ARCH-M models is that the residuals are not serially correlated. To test this hypothesis, the Ljung-Box test is applied with 12 lagged residuals, yielding the statistic $Q_1(12) = 15.37$ which is asymptotically distributed as $\chi^2_{12}$ under the null. The conclusion is that serial correlation is not present in the residuals, since the critical value of $\chi^2_{12}$ at the 5% level is 21.03. In addition, a Ljung-Box test with squared lagged residuals is performed following Bollerslev (1987), giving a non significant statistic of $Q_2(10) = 8.90$. The reason for conducting this test is to verify that no residual ARCH is present.

The log likelihood function of the model to be reestimated assuming a Gram-Charlier distribution, is thus given by

$$\ln L(\phi) = \sum_{t=1}^{T} \ln L_t(\phi), \qquad \ln L_t(\phi) = -\ln(h_t) - \frac{\varepsilon_t^2}{2h_t^2} + \ln \psi(u_t), \quad [14]$$

where $u_t \equiv \varepsilon_t / h_t$. Maximizing with respect to the parameters, and selecting the model with the lag structure giving the highest likelihood value yields the following estimates:

$$\begin{aligned} y_t &= \underset{(-3.05)}{-0.018} + \underset{(2.33)}{0.223} h_t + \varepsilon_t \\ h_t^2 &= \underset{(1.70)}{0.0003} + \underset{(8.72)}{1.440} \sum_{i=1}^{6} w_i e_{t-i}^2, \qquad w_i = (7-i)/21 \\ \lambda_3 &= \underset{(-1.87)}{-0.926}, \quad \lambda_4 = \underset{(4.76)}{4.057} \\ \ln L &= 109.32 \end{aligned} \quad [15]$$

The same diagnostic test for autocorrelation is conducted as before, resulting in a Ljung-Box statistic of $Q_1(12) = 16.22$ which is not significant at the 5% level.

It is clear from [15] that all parameter estimates in the conditional mean and variance equations are significant at the 5% level, as are the coefficients of excess skewness and kurtosis, $\lambda_3$ and $\lambda_4$. The intercept in the conditional mean, which is equivalent to the expected riskless holding yield, is -0.018 % per 60-day period. The expected term premium with perfect forecasts, i e when past innovations are zero, is -0.014 per cent at 60-day rates. These rates correspond to only about -0.10% per annum, which of course is very small, considering the existence of transaction costs. Although small, the intercept in the conditional mean equation is nevertheless statistically different from zero. This negative excess holding yield might suggest some kind of underlying preferred habitat behaviour, in the sense that investors appear to prefer the 120 day t-bill over the 60 day bill. However, the coefficient of the time varying risk premium (δ) is positive which means that the excess holding yield as it is defined becomes larger as risk increases. Greater risk in the form of higher variance leads to a larger positive risk premium and, given a large enough variance, to a positive total term premium. It therefore seems that in times of high volatility investors leave their preferred habitat of 120 day bills to a certain extent and switch to instruments of shorter maturity, which also intuitively seems reasonable.

The estimated parameter of the risk premium is substantially smaller than the coefficients estimated by Engle, Lilien and Robins (1987) for short term t-bills in the United States. Their estimates are 0.80 for 60 day vs 30 day bills, and 0.69 for 180 vs 90 day t-bills. One possible explanation for this difference could be that investors in the Swedish market are less risk averse.

As for the conditional variance, one can conclude that ARCH effects are in fact present since the coefficient $\alpha$ is nonzero. As in the American estimates of Engle *et al*, the ARCH parameter is above one which means that the unconditional variance of the excess return is infinite.[6] These estimates of $\alpha$ are greater than the estimate of Lee and Tse (1991), who modelled the term premium between one and two month rates of the Singapore Asian US Dollar market. Their estimate of the ARCH coefficient was 0.90 for an ARCH(8)-M model, assuming a Gram-Charlier error distribution.

## 5.2 Further Misspecification Tests

To check for misspecification in the variance equation, a generalized ARCH in mean (GARCH(1,1)-M) model is considered, where the conditional variance is assumed to depend on past squared innovations and past conditional variances, (equation [2]). As in the case of the ARCH-M model, estimation is carried out assuming a Gram-Charlier type of distribution, yielding the following result:

$$\begin{aligned}
y_t &= \underset{(-1.90)}{-0.030} + \underset{(0.72)}{0.149} h_t + \varepsilon_t \\
h_t^2 &= \underset{(1.31)}{0.0003} + \underset{(3.56)}{0.263}\, \varepsilon_{t-1}^2 + \underset{(17.84)}{0.850} h_{t-1}^2 \\
\lambda_3 &= \underset{(-1.67)}{-1.420}, \qquad \lambda_4 = \underset{(5.45)}{5.745} \\
\ln L &= 107.56
\end{aligned} \qquad [16]$$

Here, one can see that the coefficient of the risk premium is no longer significant, while the volatility persistence effects still are clearly present, as demonstrated by the two significant GARCH-parameters. The infinite unconditional variance property of the ARCH model [19] is also found in the GARCH model. However, the GARCH(1,1)-M model gives a lower log likelihood value than the ARCH(6)-M. Therefore, if two different standard selection criteria are used to compare the models, namely the Akaike Information Criteria (AIC) and the Schwartz Criteria (SC), this results in

---

6 The unconditional variance is defined as $\sigma^2 = \gamma/(1-\alpha)$. The estimates of Engle et al of the ARCH parameter for the 60 vs 30 day and the 180 vs 90 day excess holding yield were 1.13 and 1.64 respectively, thus also implying infinite unconditional variance. The conditional variance is still finite, however.

rejection of the GARCH-M model. The AIC values are -206.64 for the ARCH-M model and -201.11 for the GARCH-M, while the SC gives values of -195.17 and -187.73 respectively. The selection rule is to pick the model for which the criteria are minimized.

Another form of misspecification concerns the possibility of important explanatory variables being omitted from the model. Information variables suggested in the literature include yields for different maturities, the yield spread which was considered by Mankiw and Summers (1984), and lagged excess holding yield which was proposed by Leiderman and Blejer (1987). As mentioned in the previous section, factors which are important for a small open economy such as foreign interest rates and exchange rates should also be considered. Also, the exact relationship between the excess holding yield and the conditional variance is not known. It is therefore possible that the conditional variance or perhaps the logarithm of the conditional standard deviation should enter the mean equation instead of just the conditional standard deviation.

To test for this kind of misspecification, model [15] is reestimated with different functions of the conditional standard deviation in the mean, and with a number of different additional information variables, added one at a time. Table 3 summarizes the results in the form of log likelihood values and figures for AIC and SC.

*Table 3. Augmented models*

| Added variable | ARCH(6)-M log L | AIC | SC |
|---|---|---|---|
| (None) | 109.32 | -206.64 | -195.17 |
| $h_t^2$ | 107.99 | -203.98 | -192.51 |
| $\ln(h_t)$ | 104.84 | -197.68 | -186.21 |
| 60 day yield | 113.15 | -212.29 | -198.91 |
| 120 day yield | 111.88 | -209.77 | -196.39 |
| 120/60 day yield spread | 114.86 | -215.72 | -202.33 |
| $y$ lagged 1 period | 109.97 | -205.94 | -192.70 |
| $y^2$ lagged 1 period | 107.31 | -200.62 | -187.38 |
| ECU (difference) | 110.78 | -207.55 | -194.17 |
| German 90 day Eurorate | 110.48 | -206.96 | -193.57 |

The expressions in the first column are the new explanatory variables which are added to model [15]; $h_t^2$ and $\ln(h_t)$ denote the conditional variance and the logarithm of the conditional standard deviation respectively in the mean equation, $y$ is the excess holding yield as in [6], ECU denotes the change in a 60 day interval of the exchange rate between the Swedish Krona and the theoretical ECU.

Appendix 2 presents the values of the estimated parameters for the augmented models. It is clear from table 3 that the conditional standard deviation is the most appropriate risk measure of the three alternatives. It is also evident that some of the additional variables provide significant contributions to the model. Nevertheless, the risk-premium parameter for the standard deviation in the conditional mean model is always positive, although the magnitude varies. An ARCH(6)-M model with the 120/60 day yield spread included in the mean equation gives the highest log likelihood value and the lowest AIC and SC statistic. However, as can be seen in appendix 2, in this model the parameter for excess skewness is no longer significant at the 10% level. Therefore, this parameter is dropped and the model is reestimated, giving the final preferred model for the excess holding yield between 120 and 60 day t-bills:

$$\begin{aligned}
&y_t = \underset{(-3.65)}{-0.015} + \underset{(6.61)}{0.338} h_t + \underset{(4.96)}{0.585}(R_t - r_t) + \varepsilon_t \\
&h_t^2 = \underset{(1.89)}{0.0002} + \underset{(10.50)}{2.128} \sum_{i=1}^{6} w_i \varepsilon_{t-i}^2 , \quad w_i = (7-i)/21 \\
&\lambda_4 = \underset{(8.25)}{6.911} \qquad Q_1(12) = \underset{(p=0.36)}{13.137} \qquad Q_2(12) = \underset{(p=0.73)}{8.620} \qquad\qquad [17] \\
&\ln L = 114.67 \qquad \text{AIC} = -217.34 \qquad \text{SC} = -205.87
\end{aligned}$$

Mankiw and Summers (1984) find for American data that the yield spread is an important factor in explaining the excess holding yield, and this is interpreted as a failure of the expectations hypothesis. Adding the yield spread to their ARCH-M model for 180 vs 90 day t-bills, Engle, Lilien and Robins (1987) also find this to be a significant explanatory variable for the excess holding yield. Their estimate of the parameter for the yield spread is 0.392 for quarterly data.

To summarize, the ARCH(6)-M model augmented with the yield spread is the final preferred model, assuming a Gram-Charlier type distribution. The parameters of the conditional mean and variance are all significant. The expected riskless return is negative, possibly suggesting that investors have a preferred habitat of 120 day t-bills, when compared to 60 day bills. The positive coefficient for the standard deviation in the mean equation implies that as volatility increases, investors leave their preferred habitat and turn to bills with shorter time to expiration.

# 6 Empirical Results for 180 vs 90 Day T-bills

## 6.1 The Ordinary ARCH-M model

In this section an attempt will be made to model the excess holding yield between 180 day and 90 day t-bills in the same way as in the previous section. The parameters for the ARCH-M model are estimated assuming normality. The number of lagged squared residuals in the weighted average of the conditional variance equation is allowed to vary between one and 12, in order to find the lag structure which maximizes the likelihood function. In this case a maximum is found when including only one lagged squared residual:

$$\begin{aligned} y_t &= \underset{(0.09)}{0.022} - \underset{(-0.33)}{0.416} h_t + \varepsilon_t \\ h_t^2 &= \underset{(2.73)}{0.028} + \underset{(1.37)}{0.401} \varepsilon_{t-1}^2 \\ \ln L &= 35.90 \quad \text{AIC} = \text{-}63.80 \quad \text{SC} = \text{-}57.81 \end{aligned} \qquad [18]$$

Tests for normality show that the assumption of normality is reasonable, and there is therefore no need to switch to a Gram-Charlier or any other distribution.[7] As can be seen, none of the parameter estimates in [18] are significant at the 5% level, except the intercept in the conditional variance equation. There is merely a weak indication of a time varying variance, as the ARCH parameter is significant only at the 10% level. The Ljung-Box statistic is 20.066 for 12 lagged residuals, and 14.155 for 12 lagged squared residuals, neither of which are significant at the 5% level. This suggests that any ARCH effects present in this return series are incorporated in model [18]. However, to check for possible misspecification in the conditional variance, a GARCH(1,1)-M model is estimated. The result is again insignificant parameters, as well as a negative GARCH parameter and a lower log likelihood value.

Tests for omitted variables in the conditional mean are carried out in the same way as in the previous section. Results may be found in appendix 3. The conclusion from these tests is that none of the added variables are significant at the 5% level, and that in only one case is the SC-value marginally lower than in model [18].

Since the coefficient for the risk premium (δ) is insignificant in all of the cases, this parameter is dropped, and the model is reestimated as a normal ARCH model. The result, after maximizing the log likelihood with respect to

---

[7] The skewness and kurtosis of the standardized residuals is -0.34 and 3.14 respectively, giving an insignificant value of the Bera-Jarque statistic of 0.66 (prob-value = 0.72).

the number of lagged squared residuals included, is the following parameter estimates:

$$y_t = \underset{(-1.89)}{-0.059} + \varepsilon_t$$

$$h_t^2 = \underset{(2.91)}{0.026} + \underset{(1.62)}{0.488}\,\varepsilon_{t-1}^2 \qquad [19]$$

$\ln L = 36.13 \quad \text{AIC} = -66.26 \quad \text{SC} = -61.78$

In this case, the log likelihood value is higher than in any of the previous models, and the SC statistic is lower, indicating that this model is superior to the others considered. The estimate of the ARCH parameter is similar to the estimate in [18], but slightly more significant. The ARCH(1)-M model is therefore rejected in favour of the ordinary ARCH(1) model. Consequently, the hypothesis that there exists a volatility-dependent time varying risk premium in the excess holding yield of 180 vs 90 day t-bills is also rejected.

The significant negative intercept in the mean equation of [19] leads to the rejection of the *pure* expectations hypothesis. It seems that investors prefer the 180 day t-bill to the shorter termed instrument, and that this preference is relatively stable. This result therefore suggests the expectations hypothesis with a constant (negative) premium.

# 7 Summary and Conclusions

It is of interest to monetary policy-makers to know whether there generally exists any time-varying risk premia in the market for treasury bills and bonds. One reason for this is that the ability to use the yield curve as a monetary indicator rests on the assumption that no such time-varying premia exists; i e the expectations hypothesis. While other determinants of a time-varying risk premium are conceivable, the most probable is the volatility. The purpose of this paper is therefore to investigate whether there is any evidence of time variation in the excess holding yield earned from holding a long term t-bill or bond and borrowing at a short rate, and whether it is possible to model it as a risk premium dependent on its variability.

Of the four sets of interest rates examined, ARCH effects are found in only two series; in the 180/90 day set, and more strongly in the 120/60 day data set. Based on this result, the excess holding yield of these two sets are modelled as ARCH-M.

The model is unsuccessful for the 180/90 day excess return since there is no support for the hypothesis that the excess holding yield is dependent on the conditional variance. There are, however, some indications of ARCH-effects present in the material. The significant negative unconditional mean suggests that investors prefer the 180 day t-bill to the 90 day bill. This result suggests the expectations hypothesis with a constant negative premium.

As for the 120/60 day excess holding yield, this is successfully modelled as ARCH-M. However, as the residuals resulting from maximum likelihood estimation, assuming a normal distribution, turn out to exhibit excess skewness and kurtosis, a distribution of a Gram-Charlier type is subsequently used for the estimation process. Estimation using this distribution does not change the result that the excess holding yield can be modelled as ARCH-M. Finally, a number of other variables which are conceivable as explanatory factors for the excess holding yield are incorporated into the model. It is found that a number of these have considerable explanatory power. The best result is achieved when the yield spread is used as an explanatory variable, in addition to the conditional standard deviation. When these extra variables are included, the estimated risk premium parameter tends to vary in magnitude. It is nevertheless always of the right sign and significantly different from zero (except in one case), suggesting that investors move from the 120 day bills to bills of shorter maturity in times of high volatility. The presence of a time varying term premium in this return series suggests the preferred habitat hypothesis. However, since the parameter estimates vary considerably as different explanatory factors are used in the model, the results should be interpreted with caution.

Considering the combined result from the four excess return series leads to the conclusion that a variance-dependent risk premium is unlikely to be present in the Swedish market for treasury bills and bonds. Furthermore, the evidence in favour of general time varying term premia is also quite weak. Therefore, with the exception of 120 vs 60 day t-bills, the conclusion is that the expectations hypothesis cannot be rejected for the data examined.

# Appendix 1. Figures

*Figure 1. Excess holding yield 60 vs 30 day t-bills*

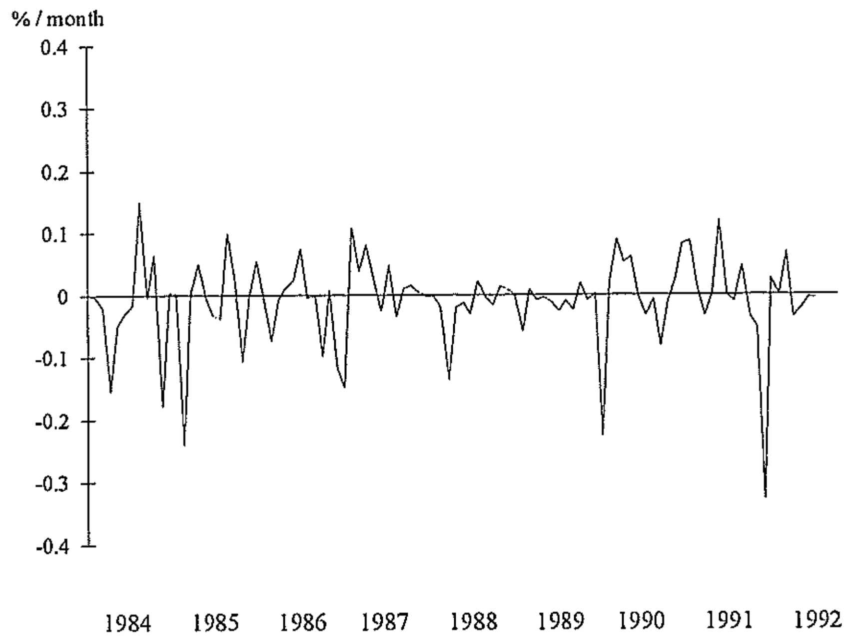



*Figure 2. Excess holding yield 120 vs 60 day t-bills*

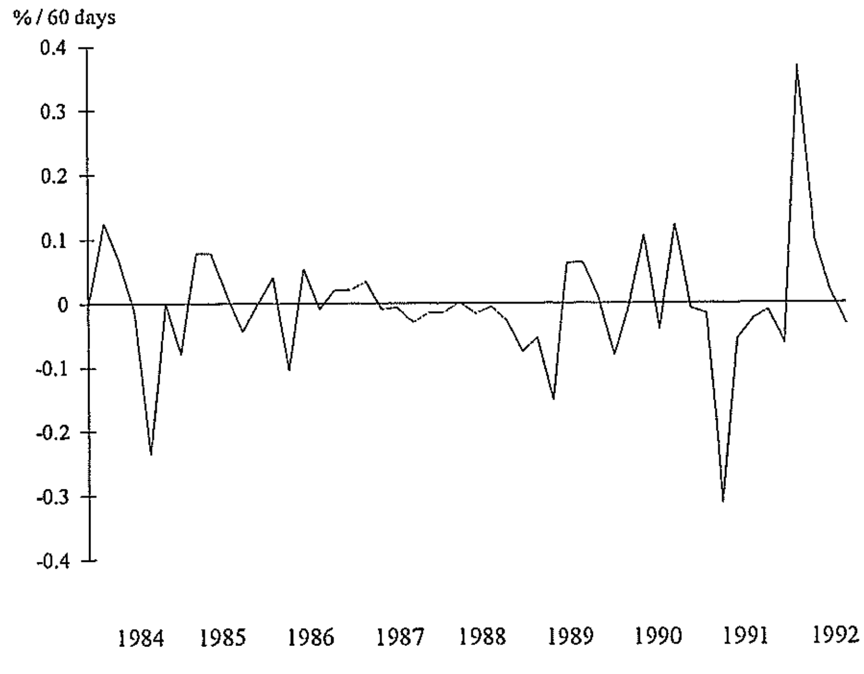


*Figure 3. Excess holding yield 180 vs 90 day t-bills*

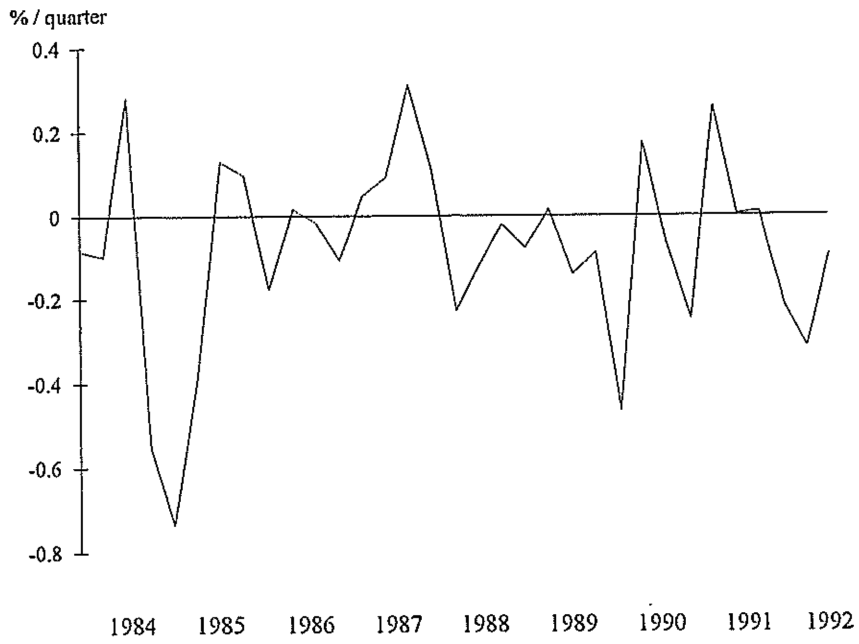
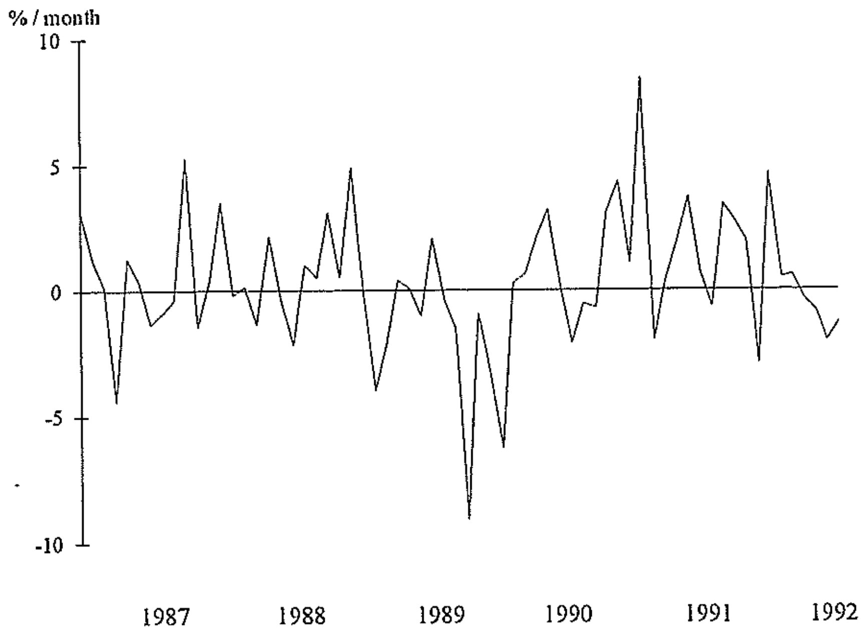



*Figure 4. Excess holding yield 10 year bonds vs 30 day t-bills*



# Appendix 2. Augmented ARCH(6)-M Models, 120/60 Day T-bills

The model used is:

$$y_t = \beta + \delta f(h_t) + \rho_j X_{jt} + \varepsilon_t, \quad h_t^2 = \gamma + \alpha \sum_{i=1}^{6} w_i \varepsilon_{t-i}^2, \quad w_i = (7-i)/21$$

$\lambda_3$ = Estimated excess skewness, $\lambda_4$ = Estimated excess kurtosis.

$X_j$ denotes the following added explanatory variables:

- $X_1$ 60 day t-bill rate,
- $X_2$ 120 day t-bill rate,
- $X_3$ Yield spread between 120 day and 60 day t-bill rates,
- $X_4$ Excess holding yield, lagged one period,
- $X_5$ Squared excess holding yield, lagged one period,
- $X_6$ Change in SEK/ECU exchange rate from two months before,
- $X_7$ German 90 day Eurorate.

| Variable | $\beta$ | $\delta$ | $\rho_j$ | $\gamma$ | $\alpha$ | $\lambda_3$ | $\lambda_4$ | $Q_1(12)$ | $Q_2(12)$ |
|---|---|---|---|---|---|---|---|---|---|
| $h_t^2$ | -0.014 | 2.231 | | .0002 | 1.715 | -1.095 | 4.145 | 14.771 | 5.754 |
| | (-2.85) | (5.21) | | (1.60) | (8.56) | (-1.93) | (3.75) | (p=0.25) | (p=0.93) |
| $\ln(h_t)$ | 0.163 | 0.069 | | .0002 | 2.913 | -0.569 | 5.028 | 10.611 | 11.87 |
| | (3.98) | (5.15) | | (0.17) | (3.09) | (-0.56) | (2.80) | (p=0.56) | (p=0.46) |
| $X_1$ | 0.058 | 0.267 | -0.090 | .0002 | 1.876 | -2.079 | 5.807 | 16.458 | 9.675 |
| | (2.50) | (4.76) | (-3.25) | (1.20) | (10.59) | (-2.88) | (5.78) | (p=0.17) | (p=0.64) |
| $X_2$ | 0.053 | 0.234 | -0.083 | .0002 | 1.765 | -1.898 | 4.995 | 16.225 | 9.618 |
| | (1.71) | (3.64) | (-2.27) | (1.22) | (9.59) | (-2.42) | (5.81) | (p=0.18) | (p=0.65) |
| $X_3$ | -0.014 | 0.353 | 0.644 | .0002 | 2.184 | 0.410 | 7.367 | 12.934 | 8.709 |
| | (-2.87) | (6.30) | (4.57) | (1.89) | (10.93) | (0.62) | (6.47) | (p=0.37) | (p=0.73) |
| $X_4$ | -0.016 | 0.212 | 0.237 | .0002 | 1.666 | -1.261 | 5.849 | 13.893 | 7.441 |
| | (-3.83) | (2.86) | (2.70) | (1.46) | (10.65) | (-2.17) | (5.10) | (p=0.31) | (p=0.83) |
| $X_5$ | -0.019 | 0.263 | -0.386 | .0002 | 1.432 | -0.959 | 4.181 | 14.056 | 7.783 |
| | (-3.34) | (2.56) | (-0.66) | (1.69) | (8.94) | (-1.89) | (5.11) | (p=0.30) | (p=0.80) |
| $X_6$ | -0.014 | 0.136 | 0.004 | .0003 | 1.648 | -1.288 | 4.805 | 16.311 | 8.378 |
| | (-2.22) | (1.46) | (1.80) | (1.82) | (8.33) | (-2.47) | (6.04) | (p=0.18) | (p=0.75) |
| $X_7$ | -0.001 | 0.259 | -0.004 | .0002 | 1.619 | -1.253 | 4.054 | 14.558 | 9.027 |
| | (-0.08) | (2.86) | (-1.55) | (1.21) | (7.66) | (-2.27) | (5.37) | (p=0.27) | (p=0.70) |

Figures in parenthesis below parameter estimates denote $t$-ratios for the null hypothesis that the parameters equal zero, while figures below Ljung-Box test statistics are $p$-values. With the exception of the first two models in the table, the conditional standard deviation is included in the mean equation.

# Appendix 3. Augmented ARCH(1)-M Models, 180/90 Day T-bills

The model used is: $y_t = \beta + \delta f(h_t) + \rho_j X_{jt} + \varepsilon_t, \quad h_t^2 = \gamma + \alpha \varepsilon_{t-1}^2$

$X_j$ denotes the following added explanatory variables:

- $X_1$ 90 day t-bill rate,
- $X_2$ 180 day t-bill rate,
- $X_3$ Yield spread between 180 day and 90 day t-bill rates,
- $X_5$ Squared excess holding yield, lagged one period,
- $X_6$ Change in SEK/ECU exchange rate from quarter before,
- $X_4$ Excess holding yield, lagged one period,
- $X_7$ German 90 day Eurorate.

| Variable | $\beta$ | $\delta$ | $\rho_j$ | $\gamma$ | $\alpha$ | $Q_1(12)$ | $Q_2(12)$ | log L | SC |
|---|---|---|---|---|---|---|---|---|---|
| $h_t^2$ | -0.003 | -1.392 | | 0.028 | 0.393 | 17.999 | 13.269 | 36.07 | -58.15 |
| | (-0.03) | (-0.57) | | (2.85) | (1.41) | (p=0.12) | (p=0.35) | | |
| $\ln(h_t)$ | -0.099 | -0.024 | | 0.027 | 0.428 | 22.181 | 14.441 | 35.82 | -57.66 |
| | (-0.28) | (-0.11) | | (2.82) | (1.50) | (p=0.04) | (p=0.27) | | |
| $X_1$ | 0.247 | -0.869 | -0.048 | 0.030 | 0.327 | 20.536 | 14.544 | 36.09 | -54.70 |
| | (0.45) | (-0.41) | (-0.62) | (2.73) | (1.14) | (p=0.06) | (p=0.27) | | |
| $X_2$ | 0.195 | -0.737 | -0.039 | 0.029 | 0.348 | 20.310 | 15.055 | 36.01 | -54.54 |
| | (0.35) | (-0.36) | (-0.46) | (2.61) | (1.13) | (p=0.06) | (p=0.24) | | |
| $X_3$ | 0.058 | -0.529 | 0.605 | 0.029 | 0.324 | 24.807 | 8.024 | 36.60 | -55.73 |
| | (0.19) | (-0.33) | (1.21) | (3.03) | (1.25) | (p=0.02) | (p=0.78) | | |
| $X_4$ | 0.105 | -0.808 | 0.073 | 0.031 | 0.322 | 19.871 | 14.753 | 33.19 | -49.06 |
| | (0.27) | (-0.42) | (0.42) | (2.70) | (1.12) | (p=0.07) | (p=0.26) | | |
| $X_5$ | -0.014 | -0.176 | -0.278 | 0.030 | 0.358 | 20.797 | 14.044 | 33.22 | -49.10 |
| | (-0.03) | (-0.08) | (-0.51) | (2.30) | (0.98) | (p=0.05) | (p=0.30) | | |
| $X_6$ | 0.065 | -0.657 | -0.027 | 0.025 | 0.424 | 16.628 | 19.959 | 37.22 | -56.95 |
| | (0.19) | (-0.37) | (-1.62) | (1.86) | (0.92) | (p=0.16) | (p=0.07) | | |
| $X_7$ | 0.142 | -0.498 | -0.017 | 0.027 | 0.385 | 24.393 | 14.234 | 36.45 | -55.41 |
| | (0.58) | (-0.43) | (-1.07) | (2.84) | (1.39) | (p=0.02) | (p=0.29) | | |

Figures in parenthesis below parameter estimates denote $t$-ratios for the null hypothesis that the parameters equal zero, while figures below Ljung-Box test statistics are $p$-values. With the exception of the first two models in the table, the conditional standard deviation is included in the mean equation.

# References

Bergman, M. (1988): "Term Premiums in the Returns from Swedish Treasury Bills", Working paper, IEF, University of Lund.

Berndt, E.K., Hall, B.H., Hall, R.E., and Hausman, J.A. (1974): "Estimation and Inference in Nonlinear Structural Models", *Annals of Economic and Social Measurement*, 4, 653-665.

Bollerslev, T. (1986): "Generalized Autoregressive Conditional Heteroskedasticity", *Journal of Econometrics*, 31, 307-327.

Bollerslev, T. (1987): "A Conditionally Heteroscedastic Time Series Model for Speculative Prices and Rates of Return", *The Review of Economics and Statistics*, 69, 542-547.

Bollerslev, T., Chou, R.Y., and Kroner, K.F. (1992): "ARCH Modeling in Finance", *Journal of Econometrics*, 52, 5-59.

Bollerslev, T., Engle, R.F., and Wooldridge, J.M. (1988): "A Capital Asset Pricing Model With Time-varying Covariances", *Journal of Political Economy*, 96, 116-131.

Buse, A. (1982): "The Likelihood Ratio, Wald, and Lagrange Multiplier Tests: An Expository Note", *The American Statistician*, 36, 153-157.

Dahlquist, M. & Jonsson, G. (1993): "The Information in Swedish Short-Maturity Forward Rates", Working paper, Institute for International Economic Studies, Stockholm University.

Ekdahl, O. & Warne, A. (1990): "Likelihood Ratio Tests of Cointegration and the Rational Expectations Model of the Term Structure of Interest Rates", Working paper, Stockholm School of Economics.

Engle, R.F. (1982): "Autoregressive Conditional Heteroscedasticity With Estimates of the Variance of United Kingdom Inflation", *Econometrica*, 50, 987-1007.

Engle, R.F., Lilien, D.M., and Robins, R.P. (1987): "Estimating Time Varying Risk Premia in the Term Structure: The ARCH-M Model", *Econometrica*, 55, 391-407.

Engle, R.F., Ng, V.K. and Rothschild, M. (1990): "Asset Pricing With a Factor-ARCH Covariance Structure", *Journal of Econometrics*, 45, 213-237.

Harvey, A. (1990): *The Econometric Analysis of Time Series*, 2nd edition, Phillip Allan, London.

Hörngren, L. (1986): "The Term Structure of Interest Rates in the Swedish Money Market", in *On Monetary Policy and Interest Rate Determination in an Open Economy*, PhD Dissertation, Stockholm School of Economics, Stockholm.

Kendall, M.G., Stuart, A. (1958): *The Advanced Theory of Statistics*, Volume 1, Charles Griffin & Co. Ltd., London.

Kroner, K.F. & Lastrapes, W.D. (1993): "The Impact of Exchange Rate Volatility on International Trade: Reduced Form Estimates Using the GARCH-in-Mean Model", *Journal of International Money and Finance*, 12, 298-318.

Lee, T.K.Y. & Tse, Y.K. (1991): "Term Structure of Interest Rates in the Singapore Asian Dollar Market", *Journal of Applied Econometrics*, 6, 143-152.

Leiderman, L. & Blejer, M.I. (1987): "The Term Structure of Interest Rates During a Financial Reform: Argentina 1977-81", *Journal of Development Economics*, 25, 285-299.

Mankiw, N.G. & Summers, L.H. (1984): "Do Long-Term Interest Rates Overreact to Short-Term Interest Rates?", *Brookings Papers on Economic Activity*, 223-242.

Pesando, J.E. (1983): "On Expectations, Term Premiums and the Volatility of Long-Term Interest Rates", *Journal of Monetary Economics*, 12, 467-474.

Shiller, R.J. (1990): "The Term Structure of Interest Rates", *Handbook of Monetary Economics, Volume I*, edited by B.M. Friedman & F.H. Hahn, Elsevier Science Publishers B.V., 627-722.

Woodward, Susan (1983): "The Liquidity Premium and the Solidity Premium", *American Economic Review*, 73, 348-361.