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Pricing Term Structure Risk in Futures Markets

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Abstract

One-period expected returns on futures contracts with different maturities differ because of risk premia in the spreads between futures and spot prices. We analyze the expected returns for futures contracts with different maturities using the information that is present in the current term structure of futures prices. A simple affine one-factor model that implies a constant covariance between the pricing kernel and the cost-of-carry can not be rejected for heating oil and German Mark futures contracts. For gold and soybean futures the risk premia depend on the slope of the current term structure of futures prices, while for live cattle futures the evidence is mixed.

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1 Introduction

In the literature on both financial and commodity futures markets¹ a large body of empirical evidence exists that futures prices differ from expected future spot prices because of risk premia (e.g. Fama, 1984a, Fama & French, 1987, Bessembinder, 1992). Investors expect to earn these spot-futures premia by taking positions in the futures market and holding these until the maturity date of the contracts. One-period expected returns on futures contracts on the other hand, do not only depend on these spot-futures premia but also on the risk premia in the futures spreads. Risk premia in futures spreads cause differences in the expected one-period returns on futures contracts with different maturities. The aim of this paper is to analyze risk premia in futures contracts with different maturities.

We define the annualized spread between the spot and futures price as the *yield*. By a no-arbitrage argument the yield is the difference between the interest rate and the net cash flow that accrues to the marginal owner of the asset. These net cash flows consist e.g. of dividends, foreign interest rates, and convenience yields, net of storage costs. Long maturity yields can be decomposed in an expected future short maturity yield plus a risk premium, in the same way as long interest rates can be decomposed in expected future short interest rates and a liquidity premium. These risk premia in the term structure of yields are equal to the differences in one-period risk premia on futures contracts with different maturities. We will maintain this dual interpretation of the risk premia throughout the paper.

Our analysis focuses on the information that is present in the current term structure of futures prices with respect to expected future yields and risk premia in the yields. This is similar to the analysis of forward currency, interest, and commodity markets in Fama (1984a,b,c) and Fama & French (1987). However, these papers focus on the predictive power of futures prices for future spot prices and on spot-futures risk premia. The approach in this paper is different, because we study the differences in one-period risk premia between futures contracts with different maturities. A related part of the literature focuses on the relation between yields and spot price changes (see e.g. Fama & French, 1988, Bessembinder et al., 1995a), but it does not consider the yields and yield changes themselves. The aim here is to fill this

¹We will ignore the difference between futures and forward contracts. For a detailed discussion of the difference between these two types of contracts, see, e.g., Cox, Ingersoll, & Ross (1981).

gap.

Pricing forward and futures contracts for maturities that are not (yet) traded, or pricing other derivative securities on the assets underlying the futures contracts, requires knowledge about the covariance of the pricing kernel and the yields. These covariances can be derived from a simple affine one-factor model for the yields, that encompasses both a Vasicek and a Cox-Ingersoll-Ross (CIR) like model as special cases. It is only in the special case that the Vasicek-like model is valid, that the covariances of the kernel with the yields are constant. This implies that risk premia are constant and that the term structure of futures prices contains no information about risk premia in the yields. With a CIR-like specification the covariance of the kernel and the yields are dependent on the current level of the short yield, implying that the risk premia depend on the current slope of the term structure of futures prices.

The empirical analysis is conducted for five futures contracts: gold, heating oil, live cattle, soybeans, and German Mark futures contracts. We use observations both at a low frequency, which is equal to the frequency of the delivery dates of the specific contract, and at a daily frequency. The results show that for heating oil and German Mark futures the data are consistent with a Vasicek-like model for the term structure of yields. For heating oil we can not reject the hypothesis that the risk premia in the term structure of yields are constant. Also, for these contracts the estimated risk premia are always negative. This implies that one-period expected returns on heating oil futures are lower for the longer maturity contracts. For German Mark futures we can not reject the hypothesis that the premia are zero. Finally, gold and soybean futures show evidence that risk premia depend on the current slope of the futures term structure, while the evidence for live cattle futures is mixed. Of course, these results have clear implications for hedging and portfolio decisions, as well as for pricing other derivative securities.

The outline of this paper is as follows. In section 2 we will show how to derive information about risk premia from the term structure of futures prices. Section 3 shows the implications of a simple one-factor model for the term structure of futures prices. In Section 4 we will present the empirical analysis. Finally, Section 5 contains the concluding remarks.

2 The information in futures prices with different maturities

When buying an asset on the spot market at time t and simultaneously taking a short position in the futures market for delivery at time $t + n$, an investor can lock in a certain return if both the spot and the futures position are held until maturity². We will refer to this certain return as the (continuously compounded) *yield*, $y_t^{(n)}$:

$$y_t^{(n)} \equiv \frac{f_t^{(n)} - s_t}{n}, \quad (1)$$

where $f_t^{(n)}$ is the log futures price for delivery at $t + n$, and s_t is the log spot price. This yield is also known as the *annualized spread* or the *slope* of the futures term structure. By a no arbitrage argument, the yield is equal to the n -period interest rate minus the net cash flow (as a percentage of the spot price) that accrues to the marginal owner of the asset. This net cash flow consists for instance of dividends, foreign interest rates, or convenience yields, net of any storage costs that have to be paid for holding the asset.

Similarly, the *forward yield* (or *annualized forward spread*), $h_t^{(k,n)}$, is the yield that an investor can earn from time $t + k$ to $t + n$, which he can lock in at time t by taking simultaneously a long position in a futures contract that matures at $t + k$, and a short position in a futures contract that matures at $t + n$:

$$h_t^{(k,n)} \equiv \frac{f_t^{(n)} - f_t^{(k)}}{n - k} = \frac{ny_t^{(n)} - ky_t^{(k)}}{n - k}. \quad (2)$$

It is obvious that the term structure of (forward) yields can be derived from spot and futures prices in the same way that the term structure of (forward) interest rates can be derived from bond and bond futures prices.

Focussing on one-period changes in spot and futures prices, the forward yield $h_t^{(1,n)}$ can be decomposed in the expected future yield $E_t[y_{t+1}^{(n-1)}]$ and a risk premium $\theta_t^{(n)}$:

$$h_t^{(1,n)} \equiv \frac{ny_t^{(n)} - y_t^{(1)}}{n - 1} = E_t[y_{t+1}^{(n-1)}] + \frac{\theta_t^{(n)}}{n - 1}. \quad (3)$$

In terms of spot and futures prices, equation (3) can be rewritten as:

$$\theta_t^{(n)} = E_t[s_{t+1} - f_t^{(1)}] - E_t[f_{t+1}^{(n-1)} - f_t^{(n)}]. \quad (4)$$

This equation shows that the risk premium $\theta_t^{(n)}$ equals the expected one period return on a spreading strategy that involves a long position in a futures

²We will ignore transaction costs that are associated with possible delivery.

contract with one period to maturity and a short position in a futures contract with n periods to maturity. Alternatively, $-\theta_t^{(n)}$ is the expected one period return on a futures contract with n periods to maturity, in excess of the return on a one period futures contract. Thus, the different premia $\theta_t^{(n)}$ that are present in the term structure of yields, also show up as the differences in the one period expected returns on futures contracts with different maturities.

Although the risk premia $\theta_t^{(n)}$ ultimately arise from uncertainty in the *yields*, i.e., in dividends, convenience yields, etc., equation (4), which is in terms of spot and futures *prices*, provides a convenient way of communicating empirical results with respect to the term structure. Equation (4) shows that the forward spread between the n -period futures price and the 1-period futures price, $f_t^{(n)} - f_t^{(1)}$, contains information about next period's $(n - 1)$ -period spread, $f_{t+1}^{(n-1)} - s_{t+1}$, and about the risk premium $\theta_t^{(n)}$. It is well known from a series of papers by Fama (1984a,b,c, 1986) that the extent to which variation in both the future spread $f_{t+1}^{(n-1)} - s_{t+1}$, and variation in the risk premium $\theta_t^{(n)}$ show up in the variance of the forward spread $f_t^{(n)} - f_t^{(1)}$ can be analyzed by the complementary regressions:

$$\begin{aligned} f_{t+1}^{(n-1)} - s_{t+1} &= \alpha_1 + \beta_1(f_t^{(n)} - f_t^{(1)}) + \eta_{1,t+1}, & (5) \\ (s_{t+1} - f_t^{(1)}) - (f_{t+1}^{(n-1)} - f_t^{(n)}) &= \alpha_2 + \beta_2(f_t^{(n)} - f_t^{(1)}) + \eta_{2,t+1}. \end{aligned}$$

The error term $\eta_{1,t+1}(= -\eta_{2,t+1})$ is the prediction error of next period's spread, i.e. $\eta_{1,t+1} = (f_{t+1}^{(n-1)} - s_{t+1}) - E_t[f_{t+1}^{(n-1)} - s_{t+1}]$. The first regression in (5) answers the question whether forward spreads have power to predict future spreads. If this is the case, then this will result in an estimate of β_1 which is different from zero. The predictive power of forward spreads for future spreads is diminished if there is variation in the risk premia $\theta_t^{(n)}$ that shows up in the forward spread. This will result in the estimate of β_2 in the second regression in (5) being different from zero (and the estimate of β_1 being different from one).

The analysis presented in this section isolates the information that is present in the term structure of futures prices with respect to expected future yields and risk premia in yields. Earlier studies concentrated on the information in futures prices with respect to future spot prices and risk premia in spot market returns (e.g. Fama, 1984a,b,c, 1986, Fama & French, 1987) or on the interaction of yields and spot prices (e.g. Fama & French, 1988, Bessembinder et al., 1995a,b), rather than on the yields themselves, as we do here. In the next section we will show that in a simple one-factor model for the term structure of yields, the covariances of the yields with the pricing kernel can be derived from the term structure of futures prices. Knowledge of these covariances can be used to price many other derivative securities on

the asset underlying the futures contracts. The one-factor model will also provide testable implications for the coefficients α and β in (5).

3 A one-factor model for the term structure of yields

3.1 An affine one-factor model

In equilibrium, in frictionless markets, the risk premium $\theta_t^{(n)}$ is determined by the covariance of $y_{t+1}^{(n-1)}$ and the stochastic discount factor, or pricing kernel, m_{t+1} :

$$\theta_t^{(n)} = Cov_t[m_{t+1}, (n-1)y_{t+1}^{(n-1)}]. \quad (6)$$

The stochastic discount factor is known to be proportional to the marginal (derived) utility of rational agents, given their optimal portfolio and consumption choice (see e.g. Ingersoll, 1987). It is straightforward to show that equation (6) follows from the first order conditions of the portfolio and consumption problem. Using a suitable specification of the process for the short yield, $y_t^{(1)}$, it is possible to characterize the covariances of the pricing kernel with the yields and to make testable statements about the term structure of futures prices. In this section we will show the implications of an affine one-factor model for the term structure of yields. This discussion closely follows the one-factor models for the term structure of interest rates as outlined for instance in Campbell (1994).

Assume that the short yield, $y_t^{(1)}$, follows a first order autoregressive process, with possibly heteroskedastic innovations, of the following form:

$$y_{t+1}^{(1)} = \mu + \rho(y_t^{(1)} - \mu) + ((1 - \omega) + \omega y_t^{(1)})\varepsilon_{t+1}. \quad (7)$$

Here $0 \leq \omega \leq 1$ and ε_{t+1} is an *i.i.d.* random variable with $E_t[\varepsilon_{t+1}] = 0$, and $Var_t[\varepsilon_{t+1}] = \sigma_\varepsilon^2$. We will also assume that the covariance of ε_{t+1} with the stochastic discount factor is constant, i.e. $Cov_t[\varepsilon_{t+1}, m_{t+1}] = \sigma_{\varepsilon m}$. Although the process for $y_t^{(1)}$ is exogenously given here, (7) may very well be the reduced form of a model in which $y_t^{(1)}$ is the (endogenous) result of the optimal decisions about consumption, production, and storage made by rational agents. Since here the aim is to derive the information about risk premia and future yields that is present in the term structure of futures prices, we take the model for the short yield as given.

The process in (7) encompasses two special cases if ω is either 0 or 1. If $\omega = 0$, then the process in (7) is similar to the process for the short term

interest rate specified by Vasicek (1977). In this case, (7) is also similar to the model for the convenience yield in Brennan (1991), referred to as the *autonomous convenience yield* model. If $\omega = 1$ then we obtain a specification that is similar to the interest rate process specified by Cox, Ingersoll, & Ross (CIR, 1985). If $0 < \omega < 1$, then a mixture of the two processes is obtained.

Substituting the AR(1) model in (7) into (3) and (6), we can solve all yields and risk premia as functions of the short term yield. The yield for any maturity can be written as:

$$y_t^{(n)} = A^{(n)} + B^{(n)}y_t^{(1)},$$

with:

$$\begin{aligned} A^{(n)} &= ((1 - \rho)\mu + (1 - \omega)\sigma_{\varepsilon m}) \left(1 - \frac{1}{n} \frac{(\rho + \omega\sigma_{\varepsilon m}) - (\rho + \omega\sigma_{\varepsilon m})^n}{1 - (\rho + \omega\sigma_{\varepsilon m})} \right) \quad (8) \\ B^{(n)} &= \frac{1}{n} \frac{1 - (\rho + \omega\sigma_{\varepsilon m})^n}{1 - (\rho + \omega\sigma_{\varepsilon m})}. \end{aligned}$$

Similarly, the covariances of the yields with the pricing kernel, or the risk premia, are given by:

$$\theta_t^{(n)} = (n - 1)B^{(n-1)}((1 - \omega) + \omega y_t^{(1)})\sigma_{\varepsilon m}. \quad (9)$$

Thus, all yields and risk premia are affine functions of a single factor, the short yield $y_t^{(1)}$ ³. In the special case that $\omega = 0$, i.e., when the process for the short yield is homoskedastic, the risk premia do not depend on $y_t^{(1)}$, but are constant for each value of n . For all other values of ω the risk premia will be time-varying, where all variation is captured by $y_t^{(1)}$.

In the model presented here, knowing only the spot price and one futures price (i.e., one spread), in principle allows us to determine the complete term structure of futures prices at a given date, since both the expected future yields and the covariances of the kernel with the yields depend on the short yield only. As stated before, this term structure can then be used in pricing other derivative securities on the asset underlying the futures contract. For instance, in valuing European options on an asset, under a risk neutral measure the expected spot price of the asset at the maturity date of the option will typically be replaced by the futures price of the asset, for the same maturity as the option. If a futures contract on the asset with the same maturity

³Of course it is also possible to derive the model starting from a continuous version of the process for the short yield, as in Vasicek (1977) and Cox, Ingersoll, & Ross (1981). This would only affect the constant terms in Equations (8) and (9), but not the slope coefficients.

as the option is not traded, the one-factor model can provide the necessary input to determine the option price. This is true for many other derivative securities as well⁴.

3.2 Empirical implications of the one-factor model

In the one-factor model for the term structure of yields presented above, all variation in (expected) yields and risk premia is due to variation in one factor, which may be the short yield. Since the regressions in (5) are specified in terms of spreads (yields) only, the regression parameters are fully determined by the model parameters given above. In particular, if the one-factor model is valid, the slope coefficients β_1 and β_2 from (5) can be written as:

$$\beta_1 = \frac{\rho}{\rho + \omega\sigma_{\varepsilon m}}, \quad \beta_2 = \frac{\omega\sigma_{\varepsilon m}}{\rho + \omega\sigma_{\varepsilon m}}, \quad (10)$$

while the constant α_1 ($\alpha_2 = -\alpha_1$) is given by:

$$\alpha_1 = \frac{1 - \rho^{n-1}}{1 - \rho}(1 - \omega)\sigma_{\varepsilon m}. \quad (11)$$

For one thing, these solutions show that in the one-factor model the slope coefficients in (5) do not depend on the maturity n , but are the same for all spreads along the term structure. Differences in maturity only show up in the intercepts. The absolute values of the intercept are increasing functions of the maturity.

If the process of the short yield is homoskedastic, i.e., $\omega = 0$, and if $\rho \neq 0$, then the slope coefficient β_1 will be equal to one, and β_2 will be equal to zero. Thus, if the short yield follows a Vasicek-like process with $\rho \neq 0$, i.e., the short yield is not expected to revert to its long term average immediately, then all variation in the forward spreads is due to variation in expected future spreads, which could be expected since the homoskedastic model implies constant risk premia. If $\omega = 0$ and $\rho \neq 0$, then the intercept α_1 gives a direct estimate of the risk premium $\theta^{(n)}$.

The opposite extreme case where β_1 is zero and β_2 is equal to one, is obtained if $\rho = 0$ and $\omega\sigma_{\varepsilon m} \neq 0$. In this situation expected future short yields do not depend on the current short yield, but are constant. Therefore, current spreads do not contain any information about expected future spreads, implying that β_1 will indeed be equal to zero. The condition that $\omega\sigma_{\varepsilon m} \neq 0$ means that the short yield is heteroskedastic and therefore that variation in

⁴Similarly, Carr & Jarrow (1995) present a framework to price derivative securities based on binomial trees, that starts from the term structure of futures prices.

the short yield does cause variation in the risk premia. This variation naturally shows up in the coefficient β_2 . Also note that if $\rho = 0$, the intercepts α_1 and α_2 no longer depend on n , but are the same for all maturities.

Summarizing, the fact that $\rho \neq 0$ implies that expected future short yields depend on the current short yield. This shows up in the slope coefficient β_1 in (5) being different from zero, i.e. in the forward spread having predictive power for future spreads. The fact that $\omega\sigma_{\varepsilon m} \neq 0$ implies that (co)variances of the yields $y_{t+1}^{(n)}$ depend on the current level of the short yield, $y_t^{(1)}$. This is also true for the covariance of the kernel m_{t+1} with the yields, resulting in time-varying risk premia that are affine functions of the current short yield. This shows up in the slope coefficient β_2 in (5) being different from zero, i.e. in the forward spread having predictive power for excess returns.

4 Empirical results

4.1 Description of the data

In the previous two sections it was shown how information about risk premia and future spreads could be obtained from the current futures term structure and what the implications of a simple one-factor model for the futures term structure are. In this section we will analyze the futures term structure for five contracts: gold, German Mark, heating oil, live cattle, and soybeans. The starting point of the analysis will be equation (5).

Since equation (5) requires that in every period we observe at least futures contracts with one period to maturity and one other maturity, the observation frequency of the futures contracts can not exceed the delivery frequency. As each month is not a delivery month for all futures contracts considered, the observation frequency is different for the respective futures contracts. For instance, gold futures contracts are traded for delivery in February, April, June, August, October, and December. Therefore, the observation frequency for gold futures is once every two months and *one period* refers to two months for gold futures. Table 1 contains summary statistics for the yields of the five futures for several maturities. Column 2 of Table 1 also contains information about the length of *one period*. In Section 4.2 we will present empirical results for the futures term structure based on these low frequency data. In Section 4.3 a similar analysis will be given based on daily data.

[Please insert Table 1]

We use data from the Futures Industry Institute for the period starting from March 1970 or from the start of trading in the contract, until December

1993 . Because for many commodities futures prices are more reliable than spot prices, we use the futures price at the delivery date as the spot price, rather than the spot price itself.

4.2 Empirical results for low frequency data

[Please insert Table 2]

Table 2 presents the OLS estimates for the regressions in (5). Recall that $\alpha_2 = -\alpha_1$, and $\beta_2 = 1 - \beta_1$. Therefore, Table 2 only presents estimates of α_1 and β_1 . For three contracts - heating oil, live cattle, and German Marks - the slope coefficients β_1 are less than one standard deviation away from one. If the coefficient β_1 is indeed one for these futures contracts, then this implies that all variation in the current spread $(f_t^{(n)} - f_t^{(1)})$ is due to variation in expected future spreads and not to variation in risk premia. For these contracts then, the expected next period's spread $E_t[(f_{t+1}^{(n-1)} - s_{t+1})]$ only differs from the current spread, $(f_t^{(n)} - f_t^{(1)})$, by a constant α_1 .

The constant α_1 is equal to the risk premium that investors expect to earn by holding an n -period futures contract rather than a 1-period futures contract. This is also the interpretation that follows directly from the second regression in (5). The fact that the coefficient β_2 is less than one standard deviation away from zero for the three contracts mentioned above, provides direct evidence for a constant risk premium, which is then equal to $-\alpha_2$. For instance, in buying a 1-month heating oil contract rather than a 2-month contract, an investor expects to earn an extra return of 0.73% per month. The negative risk premia imply that expected returns are always smaller for longer maturity contracts.

For gold and soybean contracts the current spreads contain information about future spreads and about risk premia, since both the estimates of β_1 and of β_2 are significantly different from zero for these contracts. Also, for these contracts, the R^2 's are usually rather high for both regressions, while for the other three contracts R_2^2 is always approximately equal to zero. Since for both gold and soybean contracts the estimated β_2 is larger than zero, the expected excess returns on long term contracts over short term contracts is smaller (larger) when the spread between long and short term contracts is large (small).

Alternatively, the results in Table 2 can be interpreted in terms of the term structure of interest rates and net cash flow yields. Assuming for instance that for heating oil and live cattle the risk and magnitude of convenience yields is far more important than of interest rates, Table 2 provides direct evidence on the term structure of convenience yields. In these terms, the

fact that the estimated coefficient β_1 (β_2) is not significantly different from one (zero) means that a version of the expectations hypothesis with constant risk premia can not be rejected for the convenience yields of heating oil and live cattle: expected future convenience yields only differ from forward convenience yields by constant risk premia. Taking the example of heating oil again: the 2-month convenience yield for heating oil equals the average of the current and next period's expected 1-month convenience yields, minus a constant premium of $\frac{1}{2} * 0.73 = 0.37\%$ per month. This represents a risk premium that is also significant in economic terms.

For German Marks we can not even reject the hypothesis that the risk premia are zero. Since the spread (yield) consists in this case of the difference of two interest rates, this suggests that the liquidity premium in the term structure of interest rates of the U.S. and Germany are approximately of the same magnitude and cancel out in the futures returns.

As pointed out in Section 3.2, if the simple one-factor model for the yields is true, then one implication is that in the regressions in (5) differences in maturity, i.e., n , show up in α_i , $i = 1, 2$, while β_i is the same for all maturities n . From the results in Table 2 it appears that for heating oil, live cattle, and German Mark futures the estimated β_i are indeed approximately the same for all maturities, which is consistent with a one-factor model. Moreover, for these contracts we can not reject the hypothesis that $\beta_1 = 1$, suggesting that a Vasicek-like model for the yields may be a reasonable model. For gold and soybean futures on the other hand, the fact that β_1 is significantly smaller than one implies that the Vasicek-specification is not valid. If the term structures of yields can be modelled with an affine one-factor model, then the short yield must include a heteroskedastic innovation as in the CIR-specification to explain the results in Table 2.

[Please insert Table 3]

Direct evidence on whether the Vasicek-model or the CIR-model provides a valid description of the term structure of yields is given in Table 3. Recall that an affine one-factor model for the term structure of yields implies that the risk premia are affine functions of the short term yield. From (4) and (9) we have that:

$$\begin{aligned} \theta_t^{(n)} &= E_t[f_{t+1}^{(n-1)} - s_{t+1}] - (f_t^{(n)} - f_t^{(1)}) \\ &= (n-1)B^{(n-1)}((1-\omega) + \omega y_t^{(1)})\sigma_{\varepsilon m} \\ &= \gamma^{(n)} + \delta^{(n)}y_t^{(1)}, \end{aligned}$$

which defines $\gamma^{(n)}$ and $\delta^{(n)}$. Based on this, Table 3 provides SUR-estimates for the following system:

$$\begin{aligned} (f_{t+1}^{(n-1)} - s_{t+1}) - (f_t^{(n)} - f_t^{(1)}) &= \gamma^{(n)} + \delta^{(n)}y_t^{(1)} + u_{t+1}^{(n)}, \\ y_{t+1}^{(1)} &= c + \rho y_t^{(1)} + ((1 - \omega) + \omega y_t^{(1)})\varepsilon_{t+1}, \end{aligned} \quad (12)$$

for $n = 1, 2, \dots, K$, and where we choose $\omega = 0$ or $\omega = 1$, i.e. a Vasicek or a CIR-like model. If ω is either one or zero, then we know the exact relationship between the coefficients $\gamma^{(n)}$, $\delta^{(n)}$, and ρ . These relationships impose nonlinear restrictions on the coefficients in (12). Table 3 also presents Wald-tests for the nonlinear restrictions imposed by the hypothesis that $\omega = 0$ (labelled *Vasicek*) and by the hypothesis that $\omega = 1$ (labelled *CIR*). The reported test-statistics are for the restrictions imposed by the two specifications on both the intercepts and the slope coefficients as well as on the slope coefficients only. Since under the hypothesis that $\omega = 1$ the AR(1) process for the short yield in (12) is heteroskedastic, the Wald test for this hypothesis is based on GLS-estimates of the system in (12). All other reported results in Table 3 are for the homoskedastic case however.

As in Table 2, the results in Table 3 show first of all that the risk premia of heating oil, live cattle, and German Mark futures do not depend on the short yield, $y_t^{(1)}$, while for gold and soybean futures they do. For heating oil and live cattle futures the risk premia are constant and significantly different from zero, while for German Mark futures, we are again not able to reject the hypothesis that risk premia are zero. The Wald test rejects the hypothesis that the Vasicek-like model ($\omega = 0$) provides a good specification of the term structure of yields for gold and soybean futures, as well as for live cattle futures, but not for heating oil and German Mark futures. If we only test the restrictions imposed on the slope coefficients however, the Vasicek-like model can be rejected for the heating oil futures as well. A formal test shows that the CIR-like model ($\omega = 1$) is rejected for all contracts except the German Mark futures. The fact that we can not reject the two models for the German Mark futures however, is due to the fact that the risk premia for German Mark futures are essentially zero. This latter conclusion is consistent with the results of e.g. Hakkio & Leiderman (1986) who can not reject the joint hypothesis of uncovered interest parity and the expectations hypothesis for monthly data. McCurdy & Morgan (1987) on the other hand, do reject this joint hypothesis using weekly data. Summarizing, except for heating oil and German Mark futures, neither the Vasicek-like model, nor the CIR-model provides a good specification of the term structure of yields for the futures contracts considered here.

4.3 Empirical results for daily data

As pointed out above, if we base our analysis on the regressions in (5) then we need to observe $y_t^{(1)}$ every period, implying that the frequency of the observations can not exceed the frequency of the delivery dates. A drawback of using those low frequency data is that much information is lost because only a limited number of the observations can be used. On the other hand, using daily data the condition that there are observations for $y_t^{(1)}$ every period is clearly not fulfilled, since futures contracts expire at most once per month. A similar analysis as in the preceding section can be performed for daily data as well however, if we start from the decomposition of $h_t^{(k,n)}$ rather than from the decomposition of $h_t^{(1,n)}$:

$$\begin{aligned}
 (n - k)h_t^{(k,n)} &= ny_t^{(n)} - ky_t^{(k)} & (13) \\
 &= E_t[(n - k)y_{t+k}^{(n-k)}] + \Theta_t^{(k,n)}, \\
 \Theta_t^{(n,k)} &\equiv \sum_{i=0}^{k-1} \theta_t^{(n-i)}.
 \end{aligned}$$

Equation (13) is a straightforward generalization of the decomposition in (3). Again, it is convenient to express (13) in terms of spreads between futures and spot prices rather than in terms of yields. This gives the following generalization of the regressions in (5):

$$\begin{aligned}
 f_{t+k}^{(n-k)} - s_{t+k} &= \alpha_1 + \beta_1(f_t^{(n)} - f_t^{(k)}) + \eta_{1,t+k} & (14) \\
 (s_{t+k} - f_t^{(k)}) - (f_{t+k}^{(n-k)} - f_t^{(n)}) &= \alpha_2 + \beta_2(f_t^{(n)} - f_t^{(k)}) + \eta_{2,t+k}.
 \end{aligned}$$

Obviously, the interpretation of (14) is completely analogous to the interpretation of (5). The first regression in (14) answers the question whether the current forward spread between $f_t^{(n)}$ and $f_t^{(k)}$ has predictive power for the $(n - k)$ -period spread k periods ahead. If this is the case, then β_1 will be different from zero. The second regression investigates whether there is variation in the k -period risk premium $\Theta_t^{(k,n)}$ that shows up in the current spread. Note that the left-hand-side of the second regression is the return on a spreading strategy that involves a long position in a k -period futures contract and a short position in an n -period futures contract, and holding these positions for k periods. The expected return on this strategy equals $-\Theta_t^{(k,n)}$.

[Please insert Table 4]

Table 4 presents estimates of the regressions in (14) for daily observations of the futures contracts. Note that n and k are measured in days now. Each

regression is based on daily observations of a pair of contracts, where the first column in Table 4 indicates which contracts are used. For instance, $1, 2$ means that the nearest-to-maturity and the second nearest-to-maturity contracts are used. Since delivery dates are fixed, if at day t we observe contracts with n and k days to maturity, then at day $t+1$ we observe contracts with $n - 1$ and $k - 1$ days to maturity (unless day t is a delivery day). This implies that the observations are overlapping for at most $n - k$ days. Therefore, the standard errors in Table 4 are calculated as in Newey & West (1987).

As with the low frequency observations, the estimates of β_1 and β_2 for heating oil and German Mark futures show that it is mainly variation in the future spreads that shows up in the forward spreads, while the forward spreads do not contain much information about risk premia, i.e. about expected holding returns on spreading strategies. The only exception with regard to these contracts are the spreads between the nearest-to-maturity and second nearest-to-maturity oil contracts, where the estimate of β_2 is significantly different from zero, indicating that the forward spread does contain information about risk premia. The results for the German Mark futures are especially close to the results of the low frequency data in Table 2, showing intercepts close to zero and slope coefficients β_1 (β_2) close to one (zero).

The estimates for live cattle in Table 4 are different from the low frequency results in that variation in risk premia now shows up in variation in the forward spreads, except for the longest-to-maturity spread. This can be seen from the estimates of β_2 which are significantly different from zero. For the daily data the results for live cattle futures are now similar to the results for gold and soybean futures. For these three contracts the risk premia depend on the slope of the current futures term structure.

Again, the results in Table 4 can be interpreted in terms of spreads and returns on spreading strategies, as well as in terms of the term structure of yields. For instance, the estimates for German Mark futures again suggest that the expectations hypothesis for the yields (i.e., for the interest *differential*) can not be rejected and that risk premia are zero. Although this is consistent with the low frequency results in the previous section as well as with the results for monthly observations in Hakkio & Leiderman (1986), these findings do not confirm the results of McCurdy & Morgan (1987) for weekly observations.

Similar to Section 3.2, we can express the regression coefficients in (14) in terms of the parameters of the affine one-factor model. Specifically, the

one-factor model implies that the slope coefficients can be written as:

$$\beta_1 = \frac{\rho^k}{(\rho + \omega\sigma_{\varepsilon m})^k}, \beta_2 = 1 - \frac{\rho^k}{(\rho + \omega\sigma_{\varepsilon m})^k}, \quad (15)$$

and that the constant α_1 ($= -\alpha_2$) equals:

$$\alpha_1 = \Psi \left\{ \frac{\varphi - \varphi^{n-k}}{1 - \varphi} - \rho^k \frac{1 - \varphi^{n-k}}{1 - \varphi} \right\}, \quad (16)$$

with $\Psi \equiv (1 - \rho)\mu + (1 - \omega)\sigma_{\varepsilon m}$,

$$\varphi \equiv \rho + \omega\sigma_{\varepsilon m}.$$

If $\omega = 0$ and $\rho \neq 0$, i.e., if the process for the short term yield $y_t^{(1)}$ is homoskedastic and the short yield does not immediately revert to its long term average, then we obtain again that $\beta_1 = 1$ and that $\beta_2 = 0$. Similarly, the opposite extreme case in which $\beta_1 = 0$ and $\beta_2 = 1$ is obtained when $\rho = 0$ and $\omega\sigma_{\varepsilon m} \neq 0$, as before. More importantly, note from (15) and (16) that both the intercepts and the slope coefficients are of the form $f \pm g^k$, with $g \geq 0$. It is computationally convenient to impose the condition that g is nonnegative. Also, this condition prevents the coefficients (and the risk premia) to show a switching pattern when the number of days to maturity is either odd or even. Table 5 reports estimates of the regressions in (14) in which the parameters are functions of k , the maturity of the nearest-to-maturity contract:

$$\begin{aligned} f_{t+k}^{(n-k)} - s_{t+k} &= (a_1 \pm c_1^k) + (b_1 \pm d_1^k)(f_t^{(n)} - f_t^{(k)}) + \eta_{1,t+k} \\ (s_{t+k} - f_t^{(k)}) - (f_{t+k}^{(n-k)} - f_t^{(n)}) &= (a_2 \pm c_2^k) + (b_2 \pm d_2^k)(f_t^{(n)} - f_t^{(k)}) + \eta_{2,t+k}, \end{aligned}$$

where we impose that $c_i > 0$ and $d_i > 0$, $i = 1, 2$. Note that these regressions are again complementary in that $a_1 = -a_2$, $c_1^k = -c_2^k$, $b_1 = 1 - b_2$, and $d_1^k = -d_2^k$.

[Please insert Table 5]

According to equation (15) b_1 should be equal to zero and d_1 should be equal to the estimated slope coefficient β_1 for the low frequency results in Table 3, unless the Vasicek model is true, i.e., $\omega = 0$, in which case it is also possible that $b_1 = 1$ and $d_1 = 0$. The hypothesis that $b_1 = 0$ can almost always be rejected. For heating oil and German Mark futures however, the hypothesis that $b_1 = 1$ and that $d_1 = 0$ can not be rejected, which is in accordance with a Vasicek-like model for these contracts. For most other contracts both the hypothesis that $b_1 = 0$ and that $b_1 = 1$ are rejected and

there the evidence contradicts the one-factor model. Finally, the intercept for German Mark futures appears to be equal to zero again, lending more support to the expectations hypothesis with a zero risk premia for the yields on these contracts.

5 Summary and conclusions

This paper analyzes differences in one-period risk premia for futures contracts with different maturities. These differences are caused by risk premia in the term structure of yields, where the yield is defined as the annualized spread between the futures and the spot price, which is determined by interest rates, dividend yields, convenience yields, storage costs, etc.

Our analysis focuses on the information in the current term structure of futures prices (yields) about expected future spreads (yields) and risk premia therein. Using a simple affine one-factor model for the term structure of yields, that has a Vasicek and CIR-like model as special cases, more precise statements about the information in the term structure of futures prices can be made. We show that it is only in the Vasicek specification of the term structure that risk premia are constant and that the futures term structure does not contain any information about risk premia.

The empirical analysis shows that the Vasicek model can not be rejected for heating oil and German Mark futures contracts. If the Vasicek model is valid, it is relatively straightforward to derive the covariances of the pricing kernel and all yields from the term structure of futures prices. For heating oil we find evidence that risk premia are constant and negative, implying that expected one-period returns are always higher for the short maturity contracts. Of course this has clear implications for hedging and portfolio decisions. For German Mark futures we can not reject the hypothesis that risk premia are zero. Since the yield for German Mark futures is the differential between the German and U.S.-interest rates, this means that for this interest *differential* we can not reject the expectations hypothesis with zero risk liquidity premia.

For gold and soybean futures we find evidence that the expected one period futures returns depend on the slope of the futures term structure, where the expected return on long term contracts relative to short term contracts is smaller (larger) when the spread between the long and short term contracts is larger (smaller), i.e. when the term structure is more upward sloping. Finally, for live cattle futures the evidence is mixed. Although for these latter three contracts the risk premia depend on the slope of the futures term structure, the variation in the risk premia can not be captured

by a simple one-factor model such as the CIR-model. This suggests that in future research it may be useful to model the term structure of yields with a multi-factor model.

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TABLE 1
Summary statistics for yields

<i>Contract</i>		One period	Average	Std.dev.	Minimum	Maximum	AR(1)
gold ($N = 114$)	$y_t^{(1)}$	2 months	0.71%	0.34%	0.01%	1.72%	0.75
	$y_t^{(2)}$		1.03%	0.47%	0.21%	2.46%	0.89
	$y_t^{(3)}$		1.15%	0.52%	0.28%	2.78%	0.91
	$y_t^{(4)}$		1.21%	0.53%	0.31%	2.91%	0.91
heating oil ($N = 155$)	$y_t^{(1)}$	1 month	-1.27%	4.53%	-30.29%	5.66%	0.46
	$y_t^{(2)}$		-0.92%	3.48%	-23.43%	3.79%	0.52
	$y_t^{(3)}$		-0.72%	2.76%	-17.89%	3.06%	0.59
	$y_t^{(4)}$		-0.62%	2.32%	-14.64%	2.86%	0.64
live cattle ($N = 102$)	$y_t^{(1)}$	2 months	-1.78%	4.06%	-10.22%	7.80%	0.33
	$y_t^{(2)}$		-1.35%	3.00%	-8.34%	5.08%	0.49
	$y_t^{(3)}$		-0.92%	2.17%	-5.33%	3.63%	0.56
	$y_t^{(4)}$		-0.68%	1.69%	-4.04%	3.04%	0.60
soybeans ($N = 137$)	$y_t^{(1)}$	2 months	0.40%	2.30%	-9.32%	6.89%	0.30
	$y_t^{(2)}$		0.40%	2.62%	-18.01%	3.89%	0.36
	$y_t^{(3)}$		0.31%	2.74%	-20.59%	3.05%	0.47
	$y_t^{(4)}$		0.29%	2.32%	-15.47%	2.86%	0.58
German Mark ($N = 76$)	$y_t^{(1)}$	3 months	0.76%	1.00%	-1.65%	2.96%	0.73
	$y_t^{(2)}$		0.79%	0.88%	-1.55%	2.43%	0.81
	$y_t^{(3)}$		0.68%	0.83%	-1.48%	2.12%	0.81

Table 1: The table contains summary statistics for yields on futures contracts which are defined as the annualized spread between the spot and futures price. Observations are from March 1970, or from the beginning of trading in the contract, until December 1993. Average, standard deviation, maximum, and minimum are in percentage per period, where the length of one period is indicated in the first column.

TABLE 2

Premium regressions for low frequency data

$f_{t+1}^{(n-1)} - s_{t+1} = \alpha_1 + \beta_1(f_t^{(n)} - f_t^{(1)}) + \eta_{1,t+1}$ $(s_{t+1} - f_t^{(1)}) - (f_{t+1}^{(n-1)} - f_t^{(n)}) = \alpha_2 + \beta_2(f_t^{(n)} - f_t^{(1)}) + \eta_{2,t+1}$								
<i>Contract</i>	<i>n</i>	α_1	β_1	s.d.(α)	s.d.(β)	R_1^2	R_2^2	D.W.
		$(-\alpha_2)$	$(1 - \beta_2)$					
gold	2	0.09%	0.45	0.04	0.03	0.70	0.78	2.00
	3	0.14%	0.70	0.09	0.03	0.82	0.47	1.85
	4	0.18%	0.79	0.15	0.03	0.84	0.28	1.81
heating oil	2	-0.73%	1.00	0.30	0.11	0.37	0.00	2.25
	3	-0.95%	1.04	0.42	0.09	0.47	0.00	2.25
	4	-1.03%	1.00	0.45	0.07	0.56	0.00	2.20
live cattle	2	-0.84%	1.03	0.27	0.09	0.59	0.00	1.89
	3	-1.71%	1.07	0.40	0.09	0.58	0.01	1.66
	4	-1.90%	1.03	0.43	0.09	0.59	0.00	1.73
soybeans	2	-0.30%	0.15	0.19	0.05	0.06	0.66	1.54
	3	-0.58%	0.36	0.40	0.06	0.23	0.48	2.02
	4	-0.42%	0.62	0.57	0.07	0.38	0.17	2.10
German Mark	2	0.07%	1.05	0.09	0.09	0.67	0.01	2.22
	3	0.13%	0.93	0.15	0.07	0.70	0.01	2.09

Table 2: The table contains estimates for the regressions specified in the top row of the table. Observations are from March 1970, or from the beginning of trading in the contract, until December 1993. Note that one period refers to one month for heating oil contracts, two months for gold, live cattle, and soybean contracts, and three months for German Mark contracts.

TABLE 3
Tests for the Vasicek and CIR models

$$(f_{t+1}^{(n-1)} - s_{t+1}) - (f_t^{(n)} - f_t^{(1)}) = \gamma^{(n)} + \delta^{(n)} * y_t^{(1)} + u_{t+1}^{(n)}$$

$$y_{t+1}^{(1)} = c + \rho * y_t^{(1)} + \varepsilon_{t+1}$$

	n	$\gamma^{(n)}$	s.d. $(\gamma^{(n)})$	$\delta^{(n)}$	s.d. $(\delta^{(n)})$	R^2	
gold	2	0.01%	0.05	-0.94	0.07	0.65	
	3	0.01%	0.10	-0.98	0.12	0.36	
	4	0.00%	0.15	-0.96	0.19	0.20	
		c	s.d. (c)	ρ	s.d. (ρ)		
		0.17%	0.05	0.75	0.06	0.57	
		<i>Vasicek:</i>	900.30**	<i>CIR:</i>	1169.70**		
		(slopes only)	280.23**		203.96**		
heating oil	n	$\gamma^{(n)}$	s.d. $(\gamma^{(n)})$	$\delta^{(n)}$	s.d. $(\delta^{(n)})$	R^2	
	2	-0.76%	0.30	-0.03	0.07	0.00	
	3	-1.00%	0.43	-0.01	0.09	0.00	
	4	-1.06%	0.46	-0.02	0.10	0.00	
		c	s.d. (c)	ρ	s.d. (ρ)		
		-0.69%	0.34	0.46	0.07	0.22	
		<i>Vasicek:</i>	10.82	<i>CIR:</i>	15.44**		
	(slopes only)	9.40*		4.00			
live cattle	n	$\gamma^{(n)}$	s.d. $(\gamma^{(n)})$	$\delta^{(n)}$	s.d. $(\delta^{(n)})$	R^2	
	2	-0.83%	0.28	0.02	0.07	0.01	
	3	-1.52%	0.42	0.14	0.10	0.02	
	4	-1.65%	0.45	0.16	0.10	0.02	
		c	s.d. (c)	ρ	s.d. (ρ)		
		-1.17%	0.42	0.33	0.10	0.11	
		<i>Vasicek:</i>	18.80**	<i>CIR:</i>	29.71**		
	(slopes only)	6.90		6.82			

TABLE 3 (CONTINUED)

soybeans	n	$\gamma^{(n)}$	s.d. $(\gamma^{(n)})$	$\delta^{(n)}$	s.d. $(\delta^{(n)})$	R^2
	2	0.16%	0.32	-0.52	0.14	0.09
	3	0.49%	0.55	-0.62	0.24	0.05
	4	0.27%	0.63	-0.34	0.27	0.01
		c	s.d. (c)	ρ	s.d. (ρ)	
		0.24%	0.19	0.30	0.08	0.08
		<i>Vasicek:</i>	47.65**	<i>CIR:</i>	25.91**	
		(slopes only)	42.88**		21.25**	
German Mark	n	$\gamma^{(n)}$	s.d. $(\gamma^{(n)})$	$\delta^{(n)}$	s.d. $(\delta^{(n)})$	R^2
	2	0.07%	0.09	0.05	0.07	0.01
	3	-0.05%	0.15	0.11	0.12	0.01
		c	s.d. (c)	ρ	s.d. (ρ)	
		0.15%	0.10	0.77	0.08	0.57
		<i>Vasicek:</i>	0.88	<i>CIR:</i>	3.73	
		(slopes only)	0.88		0.82	

Table 3: The table contains SUR estimates for the regressions specified in the top row of the table. Vasicek is a Wald test for the restrictions imposed on the intercepts and slope coefficients by the Vasicek model, i.e. for $\omega = 0$. CIR is a Wald test for the restrictions imposed on the intercepts and slope coefficients by the CIR model, i.e. for $\omega = 1$. These test statistics are χ_5^2 except for the German Mark, where they are χ_3^2 . The line '(slopes only)' presents the test statistics for the restrictions imposed by the Vasicek and CIR models on the slope coefficients only. For the Vasicek-like model these statistics are χ_3^2 and for the CIR-like model χ_2^2 , except for the German Mark futures, where they are χ_2^2 and χ_1^2 resp. Observations are from March 1970, or from the beginning of trading in the contract, until December 1993. Note that one period refers to one month for heating oil contracts, two months for gold, live cattle, and soybean contracts, and three months for German Mark contracts.

TABLE 4
Premium regressions for daily data

$f_{t+k}^{(n-k)} - s_{t+k} = \alpha_1 + \beta_1(f_t^{(n)} - f_t^{(k)}) + \eta_{1,t+k}$ $(s_{t+k} - f_t^{(k)}) - (f_{t+k}^{(n-k)} - f_t^{(n)}) = \alpha_2 + \beta_2(f_t^{(n)} - f_t^{(k)}) + \eta_{2,t+k}$							
<i>Contract</i>		α_1	β_1	s.d.[α]	s.d.[β]	R_1^2	R_2^2
		$(-\alpha_2)$	$(1 - \beta_2)$				
gold	1, 2	0.18%	0.28	0.17	0.13	0.02	0.11
	1, 3	0.20%	0.64	0.19	0.07	0.26	0.10
	1, 4	0.24%	0.76	0.19	0.04	0.56	0.12
heating oil	1, 2	-2.31%	1.48	0.87	0.20	0.13	0.02
	1, 3	0.09%	1.06	0.31	0.11	0.66	0.01
	1, 4	-0.56%	1.20	0.51	0.14	0.70	0.06
live cattle	1, 2	1.47%	1.31	0.20	0.06	0.77	0.16
	1, 3	0.96%	1.16	0.39	0.06	0.75	0.06
	1, 4	0.68%	1.05	0.45	0.05	0.75	0.01
soybeans	1, 2	1.56%	0.62	0.21	0.09	0.36	0.17
	1, 3	1.49%	0.81	0.37	0.09	0.59	0.07
	1, 4	1.37%	0.93	0.59	0.12	0.66	0.01
German Mark	1, 2	0.04%	0.96	0.07	0.07	0.80	0.01
	1, 3	0.02%	1.00	0.09	0.05	0.90	0.00

Table 4: The table contains estimates for the regressions specified in the top row of the table. The first column indicates that i-th and j-th nearest-to-maturity contracts are used. Observations are for the period March 1970 until December 1993. For all contracts 3000 observations are available, except for heating oil, for which respectively 2626, 2442, and 2008 observations are available. Reported standard errors are Newey-West standard errors.

TABLE 5

Premium regressions for daily data with time-varying parameters

$$f_{t+k}^{(n-k)} - s_{t+k} = (a_1 \pm c_1^k) + (b_1 \pm d_1^k) * (f_t^{(n)} - f_t^{(k)}) + \eta_{1,t+k}$$

$$(s_{t+k} - f_t^{(k)}) - (f_{t+k}^{(n-k)} - f_t^{(n)}) = (a_2 \pm c_2^k) + (b_2 \pm d_2^k) * (f_t^{(n)} - f_t^{(k)}) + \eta_{2,t+k}$$

<i>Contract</i>		a_1	c_1	b_1	d_1	R_1^2	R_2^2
gold	1,2	0.15%	-0.25%	0.29	0.56	0.02	0.11
		[0.18]	[0.04]	[0.13]	[0.15]		
	1,3	0.18%	-0.58%	0.07	0.46	0.27	0.10
		[0.20]	[0.06]	[0.07]	[0.05]		
	1,4	0.24%	-0.82%	0.75	0.37	0.57	0.12
		[0.19]	[0.10]	[0.04]	[0.03]		
heating oil	1,2	-2.34%	2.34%	1.56	-0.46	0.13	0.02
		[0.87]	[0.84]	[0.32]	[0.41]		
	1,3	0.05%	0.40%	1.04	0.33	0.66	0.01
		[0.31]	[0.35]	[0.12]	[0.18]		
	1,4	-0.59%	0.84%	1.21	-0.05	0.70	0.06
		[0.53]	[0.49]	[0.15]	[0.16]		
live cattle	1,2	1.45%	0.81%	1.31	-0.13	0.77	0.16
		[0.20]	[0.22]	[0.06]	[0.08]		
	1,3	0.94%	1.04%	1.17	-0.12	0.75	0.06
		[0.39]	[0.37]	[0.06]	[0.07]		
	1,4	0.65%	1.31%	1.05	-0.01	0.75	0.01
		[0.46]	[0.45]	[0.05]	[0.06]		
soybeans	1,2	1.55%	0.39%	0.63	0.02	0.36	0.17
		[0.21]	[0.16]	[0.09]	[0.09]		
	1,3	1.47%	0.52%	0.81	0.03	0.59	0.07
		[0.38]	[0.25]	[0.09]	[0.08]		
	1,4	1.36%	0.61%	0.93	-0.02	0.66	0.01
		[0.60]	[0.38]	[0.12]	[0.09]		
German Mark	1,2	0.04%	- -	0.96	-0.04	0.80	0.01
		[0.07]	- -	[0.07]	[0.05]		
	1,3	0.02%	0.05%	1.00	-0.02	0.90	0.00
		[0.09]	[0.06]	[0.05]	[0.03]		

Table 5: The table contains estimates for the regressions specified in the top row of the table. The first column indicates that i-th and j-th nearest-to-maturity contracts are used. Observations are for the period March 1970 until December 1993. For all contracts 3000 observations are available, except for heating oil, for which respectively 2626, 2442, and 2008 observations are available. A minus sign for c_1 and d_1 means that the time intercept and the slope coefficients should be read as $a_1 - c_1^k$ and $b_1 - d_1^k$ respectively, where c_1 and d_1 themselves are always positive. Reported standard errors are Newey-West standard errors.