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The Relation Between Default-Free Interest Rates and Expected Economic Growth Is Stronger Than You Think

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ABSTRACT

The relation between default-free interest rates and expected economic growth is substantially stronger than suggested by extant literature. Futures-implied Treasury bill yield spreads are more highly correlated with future real consumption, investment, and GNP growth than spot spreads. This stronger relation arises because using futures removes a component of the spot term structure that covaries negatively with real economic growth. Treasury forward rates from spot bills contain a premium for the risk that short-sellers will default. This risk premium is negatively related to expected economic growth.

THE IDEA THAT THE optimal intertemporal allocations of consumption and investment are related to interest rates plays a central role in economics and finance. Consumption-based models tie interest rates to intertemporal marginal rates of substitution. Production-based models tie interest rates to intertemporal marginal rates of transformation (e.g., Breeden (1979, 1986) and Cochrane (1991)). Economists, though, have long been frustrated with the weak empirical relation between Treasury rates and economic growth (e.g., Hall (1988)). Yet, Harvey (1988, 1989, 1991, and 1993) and Estrella and Hardouvelis (1991) find that the spreads between long- and short-term spot Treasury yields outperform other commonly used economic variables and commercial models in predicting real consumption and production growth. This article shows that the relation between default-free interest rates and expected real economic activity is much stronger than the results of Harvey and Estrella and Hardouvelis.

The article builds upon Kamara's (1988) finding that forward rates, implied in secondary market Treasury bill yields, contain a premium for the risk that short sellers will default. This implies that spreads between long- and short-term spot Treasury bill rates contain default premiums. Since default premiums covary negatively with economic growth (Fama (1986)), they should weaken the empirical positive relation between interest rates and expected real economic growth implied by economic theory.

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The article proceeds as follows. Section I discusses the implications of Kamara (1988) for the relation between interest rates and real economic growth. Section II reports the empirical tests. Section III concludes.

I. Treasury Term Structure, Futures, and Expected Economic Growth

Economic theory (e.g., Breeden (1986), Harvey (1988), and Cochrane (1991)) suggests that the relation between real economic growth and the spread between real returns on long- and short-term Treasury bills can be written as

$$\ln(Y_{t+k}) - \ln(Y_{t+1}) = \beta_0 + \beta_1(\ln(R_{t+k}) - \ln(R_{t+1})) + \varepsilon_{t,t+k}, \quad (1)$$

where Y_{t+k} is real consumption, real investment, or real gross national product (GNP) in quarter $t + k$; R_{t+k} is one plus the perfect-market equilibrium k-quarter expected real interest rate on date t, for both borrowers and lenders; and $\varepsilon_{t,t+k}$ is the forecast error.[1] For real consumption, β_1 is the elasticity of intertemporal substitution of consumption (Hall (1988)). For real investment or GNP, β_1 is the elasticity of intertemporal transformation (Cochrane (1991, 1996)). When the term structure of expected inflation is flat, equation (1) also hold for spreads between nominal interest rates.

Equation (1) holds for all riskless and risky assets assuming that agents can costlessly trade, lend, and borrow. Although default risk is captured in equation (1), default risk creates a problem when spot (secondary market) Treasury yields are used to measure nominal returns, in that spot Treasury yields may reflect (counter-party) default risk. Unlike the stock or futures markets, there is no central market place for Treasury securities. Instead, there is an electronic network of Treasury dealers. The spot prices used in empirical studies are usually dealer quotes. Often the quotes are not actual transaction prices but reflect the dealer's subjective assessment of "where the market is" (Litzenberger and Rolfo (1984)).[2] More important for our purposes, the quotes reflect the considerations not only of buyers and sellers but also of short-sellers. Short positions in Treasury securities are not default free. (Major defaults on Treasury securities in the sample period include Drysdale and Lombard-Wall.) Default premiums (and the costs of monitoring the counterparty) vary with time to maturity and covary negatively with real economic growth (Fama (1986)). Yet, the short-selling costs charged by dealers in the secondary Treasury market are almost constant over time and across maturi-

[1] One way to get equation (2) is to assume: constant relative risk aversion, stationary jointly lognormally distributed consumption and Treasury bill returns, and conditional homoskedasticity (Ferson (1983) and Hansen and Singleton (1983)).

[2] Duffee (1996) documents problems in using quotes for some spot Treasury bills due to market segmentation. In addition, while Treasury securities have bid and ask quotes, ask quotes may be ignored because very often they are a fixed spread over the bid quote (Capozza and Cornell (1979, fn. 5), Warga (1992)).

ties.[3] Hence, these costs do not fully capture the relation between default premiums and time to maturity, nor do they fully capture the comovements of default premiums with real economic growth. Consequently, the comoments of economic growth and the spot Treasury term structure reflect the comoments of economic growth with both nominal risk-free returns and default premiums.

Kamara (1988) provides evidence that the spread between long- and short-term spot Treasury yields contain a component that covaries negatively with economic activity. Kamara studies the spread between forward rates implied in spot Treasury bill yields and the corresponding futures rates. He finds that the spread contains a premium for the risk that short-sellers of bills will default, and covaries negatively with economic activity. Futures markets have a clearing association that employs safeguards that virtually eliminate the cost of default on futures contracts. Hence, unlike spot-implied forward Treasury bill rates, futures rates are default-free.[4]

Following Kamara (1988), this article suggests a way to reduce the effects of default risk on the empirical relation between interest rates and economic growth. Consider, for example, two equivalent riskless investment strategies that yield one dollar after six months. The first strategy is to buy one 6-month spot Treasury bill with a dollar face value at a price of p_6. The second strategy, a synthetic strategy, is to buy two securities: (i) *fp* units of spot Treasury bills with 3 months to maturity, at a price of p_3 and a dollar face value per each unit; and (ii) one futures contract (calling for delivery, 3 months ahead, of a 3-month Treasury bill with a dollar face value) at a price of *fp*. Three months later, redeem the spot bills for *fp* dollars, pay the *fp* dollars in the futures market, and accept delivery of a Treasury bill with 3 months to maturity and a dollar face value. The two strategies are not exactly equivalent because futures contracts are marked-to-market daily (Cox, Ingersoll, and Ross (1981) and Richard and Sundaresan (1981)). But, Elton, Gruber, and Rentzler (1984) find that for Treasury bill futures contracts, the effect of marking-to-market is negligible.

Let the term futures-implied 6-month yield denote the yield on the synthetic strategy above. Let the term *spot* N- minus 3-month spread denote the spread between a spot N-month yield and the spot 3-month Treasury bill yield. Let the term *implied* N- minus 3-month spread denote the spread between a futures-implied N-month yield and the spot 3-month Treasury bill yield.

Consider, for example, the spread between six- and three-month Treasury bill yields. Using continuously compounded annualized returns, the spot 6- minus 3-month spread is

$$2 \cdot \ln(1/p_6) - 4 \cdot \ln(1/p_3) = 2 \cdot [\ln(p_3/p_6) - \ln(1/p_3)]. \qquad (2)$$

[3] Capozza and Cornell (1979), Elton, Gruber, and Rentzler (1984), and a Federal Reserve study (Kling (1986)) report that the cost of short-selling Treasury bills and bonds is 0.5 percent per annum. Conversations with professional Treasury traders suggest that the cost varies by counterparty credit worthiness, but is constant over time and across maturities within a "credit class."

[4] Telser and Higinbotham (1977), Edwards (1983) and Brennan (1986) discuss the implications of the futures' clearing association for futures and forward contracts.

Similarly, the implied 6- minus 3-month spread is

$$2 \cdot \ln(1/p_3 \cdot fp) - 4 \cdot \ln(1/p_3) = 2 \cdot [\ln(1/fp) - \ln(1/p_3)]. \qquad (3)$$

The spot 6- minus 3-month spread can thus be written as

$$\begin{aligned} &2 \cdot \ln(1/p_6) - 4 \cdot \ln(1/p_3) \\ &\quad = [2 \cdot \ln(1/p_3 \cdot fp) - 4 \cdot \ln(1/p_3)] + [2 \cdot \ln(p_3/p_6) - 2 \cdot \ln(1/fp)]. \qquad (4) \end{aligned}$$

That is, the spot 6- minus 3-month spread is the sum of two components: the implied 6- minus 3-month spread, and (half) the spread between the forward yield implied in 6- and 3-month spot rates (ignoring bid-ask spreads) and the corresponding futures yield.

As Kamara (1988) shows, the second component covaries negatively with economic activity. As a result, it weakens the empirical relation between the spot spread and economic growth. Consequently, economic growth should be more positively correlated with the implied spread than with the spot spread.[5]

II. Empirical Evidence

A. The Data

The data sample is from the inception of the Treasury bill futures market in 1976 through 1994. Spot interest rates are 3-, 6-, 9-, and 12-month Treasury bill bid discount rates from the daily quote sheets of the Federal Reserve Bank of New York. Futures interest rates are settlement discount rates on 3-month Treasury bill futures contracts with 3, 6, and 9 months to delivery, expiring on a quarterly basis (March, June, etc.).[6] The futures data for 1976–1989 are from the *International Monetary Market Yearbook*. The Chicago Mercantile Exchange kindly provided futures data for 1990–1994. The Appendix shows how to calculate futures-implied rates from spot and futures discount rates. The spot and futures-implied rates are converted into continuously-compounded annualized yields.

If Treasury forward rates from spot bills contain a premium for the risk that short-sellers will default, equation (4) and Kamara (1988) imply that the spot spreads between long-term and short-term yields should exceed the corresponding futures-implied spreads. This is indeed the case. The 6- minus 3-month and 9- minus 3-month spot spreads exceed the futures-implied spreads in 72 of the 75 observations, and the 12- minus 3-month spot spread exceeds the implied spread in 66 of the 74 observations. The mean differences between the spot and implied spreads are each significant at a 0.00001 level.

[5] Because the cost of buying the actual 6-month bill is higher than the cost of buying the synthetic 6-month bill (Capozza and Cornell (1979) and Elton, Gruber, and Rentzler (1984)), the spot 6-month bill yield must be higher than the futures-implied 6-month yield (Kamara (1988)). Hence, using the implied 6- minus 3-month spread instead of the spot 6- minus 3-month spread also produces a closer estimate for the 6- minus 3-month spread in frictionless markets.

[6] Spot rates are observed up to an hour after futures rates.

Figures 1 and 2 plot the one- and three-quarter growth rates of real consumption and real investment, and the corresponding lagged implied spreads. The consumption data are quarterly real personal consumption expenditures on nondurable goods and services per capita. They are calculated from monthly data on consumption and total population, including armed forces overseas. The output data are quarterly real GNP and real gross private domestic, residential and nonresidential, fixed investment. The data are in 1987 dollars, seasonally adjusted, from Citibase. All growth rates are continuously compounded and annualized. As theory predicts, the real investment and consumption growth series move with the lagged implied spread series.[7]

B. Predicting Economic Growth

Tables I through III report regressions of real consumption, real investment, and real GNP growth on lagged spot and implied spreads. Huizinga and Mishkin (1986) and Roley (1986) find that the behavior of interest rates was different during the monetary regime of October 1979 through October 1982 than before and after it. The regressions, therefore, also include the variable REGIME, an indicator variable for October 1979 through October 1982. The coefficient on REGIME is almost always negative, and in many cases statistically significant at a conventional level.[8] One assumption underlying equation (1) is that interest rates and real economic growth are conditionally homoskedastic. A significant REGIME coefficient may reflect a rejection of this assumption. This assumption is examined further below.

The adjusted R^2 of the regressions of growth on interest rates are always substantially higher using the implied spread than using the spot spread. For one-quarter growth, using the implied spread rather than the spot spread increases the adjusted R^2 from 0.10 to 0.15 for consumption, from 0.14 to 0.19 for investment, and from 0.21 to 0.28 for GNP. For two-quarter growth, the adjusted R^2 increases from 0.18 to 0.29 for consumption, from 0.12 to 0.25 for investment, and from 0.24 to 0.35 for GNP. The three-quarter growth regressions show a similar pattern. Hence, the implied spreads are significantly more informative about future real consumption, investment, and GNP growth than are spot spreads.[9]

[7] Consumption and production data are quarterly aggregates and the interest rates are point to point, but our results are similar to Harvey's (1988) for quarterly averaged real interest rates. Although economic theory implies a relation between real economic growth and real interest rates, the spreads are in nominal terms, as in Harvey (1989, 1991, and 1993) and Estrella and Hardouvelis (1991). Fama and Gibbons (1984) and Harvey (1988) find that the term structure of expected inflation is flat in short horizons.

[8] I do not reject the hypotheses that the slope coefficients of the explanatory variables do not vary across monetary regimes.

[9] I test whether the increases in the R^2 values are statistically significant, using Hotelling's (1940) test. The null hypothesis of equal explanatory power is rejected at less than the 1 percent level for one-, two-, and three-quarter consumption and investment growth, and two- and three-quarter GNP growth. It is rejected at a 2.1 percent level for one-quarter GNP growth.

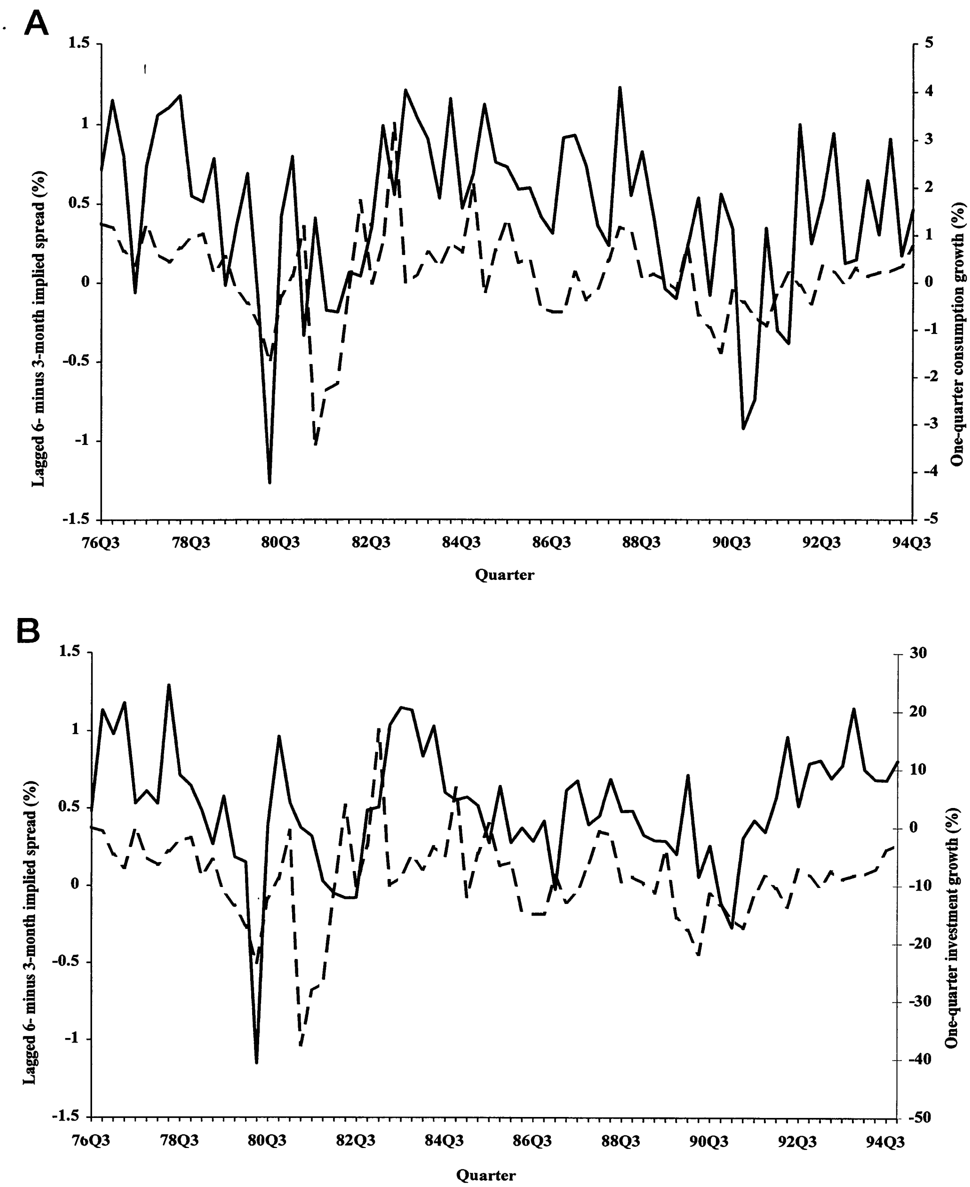
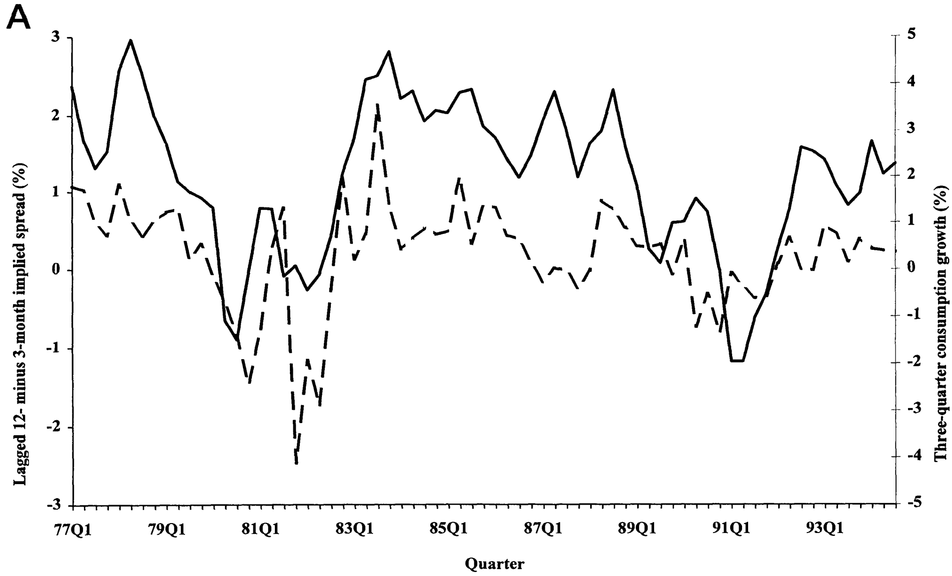


Figure 1. (A) One-quarter real consumption growth (solid line) and the spread between futures-implied 6-month Treasury bill yields and spot 3-month Treasury bill yields (dashed line): 1976–1994. The implied spread observations are lagged one quarter. Consumption growth is computed using real personal consumption on nondurable goods and services per capita. The yields and growth rates are continuously compounded and annualized. **(B) One-quarter real investment growth (solid line) and the spread between futures-implied 6-month Treasury bill yields and spot 3-month Treasury bill yields (dashed line): 1976–1994.** The implied spread observations are lagged one quarter. Investment growth is computed using real gross private domestic fixed investment. The yields and growth rates are continuously compounded and annualized.



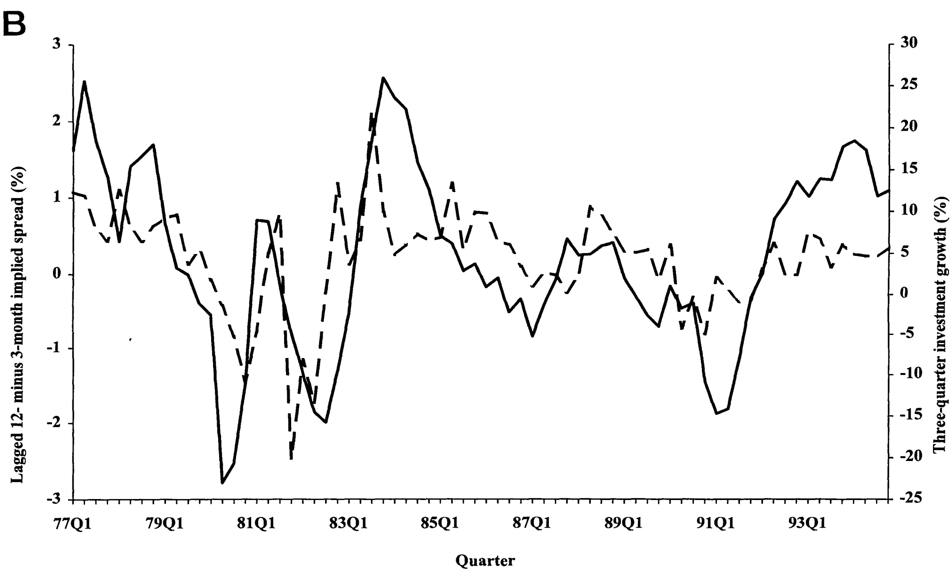


Figure 2. (A) Three-quarter real consumption growth (solid line) and the spread between futures-implied 12-month Treasury bill yields and spot 3-month Treasury bill yields (dashed line): 1976–1994. The implied spread observations are lagged three quarters. Consumption growth is computed using real personal consumption on nondurable goods and services per capita. The yields and growth rates are continuously compounded and annualized. **(B) Three-quarter real investment growth (solid line) and the spread between futures-implied 12-month Treasury bill yields and spot 3-month Treasury bill yields (dashed line): 1976–1994.** The implied spread observations are lagged three quarters. Investment growth is computed using real gross private domestic fixed investment. The yields and growth rates are continuously compounded and annualized.

Tables I through III also show that the regression coefficients on the yield spreads and their t-statistics increase as we move from the spot spread to the implied spread. For consumption data, the theoretical relation identifies the slope coefficient as the elasticity of intertemporal substitution. Using output data, the slope coefficient can be interpreted as the elasticity of intertemporal transformation. Using the implied spread rather than the spot spread, therefore, increases the estimated elasticities of intertemporal substitution and the estimated elasticities of intertemporal transformation. For example, in the one-quarter growth case, the estimated elasticity of intertemporal substitution increases from 1.29 to 1.88, and the estimated elasticity of intertemporal transformation increases from 5.88 to 10.39, using investment data. The GNP growth regressions reveal a similar pattern. The results say that an increase of 1 percent in the implied spread is, on average, accompanied by a larger increase in realized economic growth than an increase of 1 percent in the spot spread. Regressing three-quarter growth data, the estimated elasticity of intertemporal transformation in the investment regression increases from 4.83 to 6.33, but the estimated elasticity of intertemporal substitution does not increase as we move from the spot spread to the implied spread. The less clear pattern for the slope coefficients in Table III may reflect potential measurement problems in the 12-month yields.[10]

The finding that replacing the spot spread with the implied spread has a larger effect on the estimated elasticity of intertemporal transformation (in the investment regressions) than on the estimated elasticity of intertemporal substitution is evident in each of the tables. It reflects the relative magnitudes of the correlations between investment and consumption growth and the two components of the spot spread in equation (4). For investment growth, the negative correlations with the differences between the spot and implied spread are 2 to almost 4 times larger than the positive correlations with the spot spread. Whereas, for consumption growth, the correlations are of much closer magnitudes. Consequently, removing the negative component has a larger effect on the estimated elasticity of intertemporal transformation than on the estimated elasticity of intertemporal substitution.

Tables I through III further reveal that the coefficients on each of the yield spreads and on the difference between the spreads (in absolute value) are always highest for investment growth and lowest for consumption growth. This reflects the fact that the investment series exhibit relatively larger variations over time than the consumption series.

[10] Duffee (1996) reports measurement problems in secondary market quotes of 12-month Treasury bills. I repeated the tests using constant-maturity one-year spot yields instead of 12-month Treasury bill yields. The R^2 values remain substantially higher using the implied spread rather than the spot spread. Furthermore, both the estimated elasticity of intertemporal transformation and the estimated elasticity of intertemporal substitution increase substantially as we move from the spot spread to the implied spread. In addition, the multicollinearity in Table III in the regressions on both the spot spread and the difference between the spot and implied spreads disappears.

Table I

Regressions of One-Quarter Growth Rates of Consumption, Investment, and GNP on One-Quarter Lagged Spot and Implied Term Structure Spreads: June 1976–December 1994

Consumption growth is computed using real personal consumption on nondurable goods and services per capita. Investment growth is computed using real gross private domestic fixed investment. The spot spread is the spread between spot yields on 6- and 3-month Treasury bills. The implied spread is the spread between the futures-implied 6-month Treasury bill yield and the spot 3-month Treasury bill yield. The yields and growth rates are continuously compounded and annualized. REGIME is an indicator variable for October 1979 through October 1982. The t-statistics (in parentheses) are computed using Hansen's (1982) heteroskedasticity and autocorrelation consistent covariance matrix.

	Coefficients								
Variable	Consumption Growth			Investment Growth			GNP Growth		
Intercept	0.01	0.02	0.02	0.04	0.04	0.07	0.03	0.03	0.04
	(3.93)	(5.51)	(6.88)	(2.05)	(2.99)	(3.72)	(4.90)	(8.91)	(7.15)
REGIME	−0.01	−0.01	−0.01	−0.11	−0.09	−0.04	−0.04	−0.03	−0.02
	(−3.04)	(−2.45)	(−1.19)	(−2.28)	(−2.00)	(−0.88)	(−2.39)	(−2.57)	(−1.40)
Spot spread	1.29		1.78	5.88		9.45	2.91		4.07
	(2.24)		(2.62)	(1.52)		(1.93)	(2.78)		(3.70)
Implied spread		1.88			10.39			4.33	
		(2.58)			(2.07)			(3.60)	
Spot spread minus implied spread			−3.66			−27.28			−8.93
			(−3.80)			(−3.12)			(−3.41)
Adjusted R^2	0.10	0.15	0.16	0.14	0.19	0.23	0.21	0.28	0.30

Tables I through III also report regressions of the growth rates on both the spot spread and the difference between the spot spread and the implied spread. The coefficients on the differences between the spot and implied spreads are always significantly negative at a 0.002 level. Hence, as the analysis above postulates, we get a stronger positive empirical relation between real economic growth and the implied spread because we remove a component of the spot term structure that covaries negatively with expected real economic growth. Furthermore, the difference between the spot spread and the implied spread is useful for predicting economic growth even when the regression includes the spot spread. Adding it to the spot spread substantially increases the adjusted R^2 in all the regressions.

C. Robustness of Results

The tests in Tables I through III assume that the conditional variance-covariance matrix of interest rates and real economic growth is constant over time. I also examine whether the results above hold under conditional het-

Table II

Regressions of Two-Quarter Growth Rates of Consumption, Investment, and GNP on Two-Quarter Lagged Spot and Implied Term Structure Spreads: June 1976–December 1994

Consumption growth is computed using real personal consumption on nondurable goods and services per capita. Investment growth is computed using real gross private domestic fixed investment. The spot spread is the spread between spot yields on 9- and 3-month Treasury bills. The implied spread is the spread between the futures-implied 9-month Treasury bill yield and the spot 3-month Treasury bill yield. The yields and growth rates are continuously compounded and annualized. REGIME is an indicator variable for October 1979 through October 1982. The t-statistics (in parentheses) are computed using Hansen's (1982) heteroskedasticity and autocorrelation consistent covariance matrix.

	Coefficients								
Variable	Consumption Growth			Investment Growth			GNP Growth		
Intercept	0.01	0.01	0.02	0.03	0.03	0.08	0.02	0.02	0.03
	(3.26)	(4.90)	(5.27)	(1.07)	(1.61)	(4.21)	(4.01)	(6.21)	(6.33)
REGIME	−0.01	−0.00	0.00	−0.08	−0.05	0.02	−0.03	−0.02	−0.01
	(−2.89)	(−2.24)	(0.32)	(−2.86)	(−1.24)	(0.57)	(−2.34)	(−1.58)	(−0.65)
Spot spread	1.17		1.27	4.52		5.40	2.22		2.42
	(3.46)		(3.59)	(1.97)		(2.30)	(5.28)		(4.54)
Implied spread		1.44			7.78			2.81	
		(3.88)			(2.66)			(5.85)	
Spot spread minus implied spread			−2.61			−23.56			−5.38
			(−3.51)			(−4.54)			(−3.66)
Adjusted R^2	0.18	0.29	0.32	0.12	0.25	0.39	0.24	0.35	0.38

eroskedasticity. Allowing for conditional heteroskedasticity, the Consumption Capital Asset Pricing Model implies (e.g., Ferson and Merrick (1987))

$$\ln(C_{t+k}) - \ln(C_{t+1}) = \beta_0 + \beta_1(\ln(R_{k,t}) - \ln(R_{1,t})) + \tfrac{1}{2}\beta_1(\sigma^2_{k,t} - \sigma^2_{1,t}) + u_{t,t+k}, \quad (5)$$

where C_{t+k} is real consumption in quarter $t + k$, and $\sigma^2_{k,t}$ is the conditional variance on date t of $(\ln(R_{k,t}) - (1/\beta_1)(\ln(C_{t+k}) - \ln(C_t)))$.

I test equation (5) using an iterative procedure, building upon Chan (1994), to calculate properly lagged conditional variance-covariance matrices of consumption growth and *real* spot and futures-implied yields.[11] Explicitly accounting for conditional heteroskedasticity yields results similar to those reported above. Hence, the finding that the relation between economic growth and the implied spread is stronger than the relation between economic growth and the spot spread is fairly robust to model specification.[12]

[11] The conditional variance-covariance matrices use real rates because the term structure of the second moment of inflation may not be flat. Monthly CPI data from Citibase are used to calculate real yields.

[12] The superior forecasting power of the implied spread over the spot spread also holds in the presence of other predictors such as the growth variable's own lagged values.

Table III

Regressions of Three-Quarter Growth Rates of Consumption, Investment, and GNP on Three-Quarter Lagged Spot and Implied Term Structure Spreads: June 1976–December 1994

Consumption growth is computed using real personal consumption on nondurable goods and services per capita. Investment growth is computed using real gross private domestic fixed investment. The spot spread is the spread between spot yields on 12- and 3-month Treasury bills. The implied spread is the spread between the futures-implied 12-month Treasury bill yield and the spot 3-month Treasury bill yield. The yields and growth rates are continuously compounded and annualized. REGIME is an indicator variable for October 1979 through October 1982. The t-statistics (in parentheses) are computed using Hansen's (1982) heteroskedasticity and autocorrelation consistent covariance matrix.

	Coefficients								
Variable	Consumption Growth			Investment Growth			GNP Growth		
Intercept	0.01	0.01	0.02	0.02	0.03	0.09	0.02	0.02	0.03
	(3.53)	(5.75)	(6.07)	(0.91)	(1.69)	(4.79)	(3.48)	(6.04)	(6.33)
REGIME	−0.00	−0.00	0.00	−0.05	−0.02	0.03	−0.02	−0.01	0.00
	(−1.31)	(−0.12)	(0.77)	(−1.44)	(−0.67)	(1.59)	(−1.66)	(−0.98)	(0.11)
Spot spread	1.08		0.71	4.83		0.95	2.01		1.12
	(4.00)		(2.92)	(2.28)		(0.68)	(3.46)		(2.73)
Implied spread		1.07			6.33			2.13	
		(4.51)			(3.82)			(5.20)	
Spot spread minus implied spread			−2.15			−22.28			−5.12
			(−3.73)			(−6.39)			(−4.51)
Adjusted R^2	0.24	0.36	0.40	0.13	0.30	0.53	0.26	0.41	0.49

V. Conclusions

The article studies the comovements of default-free interest rates and expected future economic growth. The spot, secondary market, Treasury bill term structure contains premiums for default by short-sellers of bills. Hence, to estimate the relation between default-free interest rates and economic growth, one has to disentangle the positive covariation of the term structure of risk-free returns and economic growth from the negative covariation of default risk and economic growth. This article suggests that using futures-implied Treasury bill rates reduces the effects of default costs on the relation between interest rates and economic growth. The results show that using futures-implied term structure spreads instead of spot-only term structure spreads, purges a component that covaries negatively with expected economic growth, and substantially strengthens the empirical relation between interest rates and expected real economic activity.

The article also illustrates the informational role of futures markets. The results show that futures markets have an informational value even for policy makers and other economic agents who never trade in them.

Appendix

Calculating Futures-Implied Treasury Rates

Let P_m and d_m be the price and discount rate on a spot m-day Treasury bill with a dollar face value, where

$$d_m = (1 - P_m)\frac{360}{m}. \tag{A1}$$

One plus the (effective annualized) spot yield on the m-day bill is

$$\left(\frac{1}{P_m}\right)^{365/m} = \left(\frac{360}{360 - (d \cdot m)}\right)^{365/m} \tag{A2}$$

The futures-implied 6-month yield is the yield on the strategy of buying two securities today:

(i) $fp_{91,91}$ units of spot Treasury bills with 91 days to maturity, at a price of P_{91} and a dollar face value per each unit; and
(ii) one futures contract (calling for delivery, 91 days ahead, of a 91-day Treasury bill with a dollar face value) at a price of $fp_{91,91}$.

The strategy yields one dollar after 182 days. Hence, one plus the (effective annualized) futures-implied 6-month yield is

$$\left(\frac{1}{fp_{91,91} \cdot P_{91}}\right)^{365/182} \tag{A3}$$

The futures-implied 9-month yield is the yield on the strategy of buying three securities today:

(i) $(fp_{182,91} \cdot fp_{91,91})$ units of spot Treasury bills with 91 days to maturity, at a price of P_{91} and a dollar face value per each unit;
(ii) $fp_{182,91}$ futures contracts, at a price of $fp_{91,91}$ a contract, where each contract calls for delivery, 91 days ahead, of a 91-day Treasury bill with a dollar face value; and
(iii) one futures contract (calling for delivery, 182-days ahead, of a 91-day Treasury bill with a dollar face value) at a price of $fp_{182,91}$.

Note that $fp_{182,91}$ is both the number of futures contracts with 91 days to delivery that the investor purchases, and the price of a futures contract with 182 days to delivery. The strategy yields one dollar after 273 days. Consequently, one plus the (effective annualized) futures-implied 9-month yield is

$$\left(\frac{1}{fp_{182,91} \cdot fp_{91,91} \cdot P_{91}}\right)^{365/273} \tag{A4}$$

Lastly, one plus the (effective annualized) futures-implied 12-month yield is

$$\left(\frac{1}{fp_{273,91} \cdot fp_{182,91} \cdot fp_{91,91} \cdot P_{91}}\right)^{365/364}, \tag{A5}$$

where $fp_{273,91}$ is today's price of one futures contract calling for delivery, 273-days ahead, of a 91-day Treasury bill with a dollar face value.

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