

THE YIELD CURVE'S PREDICTIVE POWER ON U.S. RECESSIONS:

A SURVEY OF LITERATURE

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ABSTRACT

A negative-sloped Treasury curve is often cited in financial news articles and by Federal Reserve economists as a predictor of recessions. This report reviews previously published research examining the reliability of yield curves predicting recessions. Findings show that the yield curve inverts two or more quarters before recessions, with short-term interest rates rising above long-term interest rates. Probit regression has proven a reliable method for generating estimated probabilities of future recessions that, in turn, are useful for both monetary policy and asset allocation decision-making.

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Introduction – Theories of Yield Curve Shapes

The much-anticipated Conference Board Leading Economic Index (LEI) includes the spread between the ten-year Treasury bond yield and the federal funds rate as one of the ten input factors for compiling the LEI. Furthermore, the New York Federal Reserve's website provides a graph plotting the relationship between the one-year leading, ten-year Treasury bond/ three-month Treasury bill yield spread to U.S. recessions.¹

As early as 1965, published research studies examining the ability of the yield curve to predict economic cycles became available. A review of such research is especially timely now given that the slope of the yield curve remains positive despite weak consumer confidence and negative real wage growth coupled with increased gasoline prices, increased focus on government deficit reduction, a developing recession in Europe and slowing economic activity in China, which is a major trading partner. In the Federal Reserve Board's March 2012 meeting, the Board decided to keep in place open market purchases of Treasuries, initiated in September 2011, in order to keep long-term interest rates artificially low. Additionally, the Federal Reserve statement cited the Board's expectation of keeping short-term rates low through late 2014.

In normal economic times, the shape of the Treasury yield curve is upward or positively sloping. That is, the yield on short-term Treasuries is lower than on longer-maturity Treasuries. Three major theories, and one hybrid of the three, are regularly cited as responsible for determining the slope (or shape) of the yield curve. These theories are (1) the market expectations or pure expectations theory, (2) the liquidity premium theory, (3) the market segmentation theory and (4) the preferred habitat theory, which is a hybrid of the other three

¹http://www.ny.frb.org/research/capital_markets/Prob_Rec.pdf

theories. Before delving into research dealing with the forecasting ability of the yield-curve slope on business recessions, a brief discussion of the four theories of term structure is provided.

Under the market expectations or pure expectations theory, the shape of the yield curve is dependent on investors' expectations of the future level of short-term interest rates. Hence:

$$(1) \text{ tRL} = \sqrt[n]{(1 + {}_tR_t)(1 + {}_{t+1}r_t)(1 + {}_{t+2}r_t)\dots(1 + {}_{t+n-1}r_t)} - 1$$

The above formula hypothesizes that the current long-term bond yield (tRL) is equal to the geometric average of the current one-year bond yield (R_t) and all other future one-year bond yields expected over the tenure of the long-term bond.²

Hence, under the market or pure expectations theory, longer-term Treasury bond rates are dependent on current short-term Treasury yields and investors' current expectations of future short-term Treasury yields. If investors, as a whole, expect short-term Treasury interest rates will increase in the future, the Treasury yield curve will be upward sloping. If investors expect interest rates will decline in the future, the slope of the yield curve will be negative. This theory explains why Treasury bond yields of various maturities tend to move together. An increase in short-term rates increases the right-hand side of the equation 1, thus raising long-term rates.

Under the liquidity premium theory, the market or pure expectations theory is a major factor in determining the term structure, but expectations of future short-term interest rates are only partly responsible for the yields of longer-term Treasuries. Because expectations of future interest rates are uncertain and may be incorrect, investors demand a premium in the form of additional yield as compensation for the risk of incorrect interest rate forecasts; longer-term bond

² Lloyd B. Thomas, 2006. *Money, Banking and Financial Markets* (Ohio: South-Western), 129.

prices are more volatile than shorter-term bond prices--they exhibit greater variability over time. An equal increase in yields on all maturities will have a larger impact in depressing prices of longer-term bonds than shorter-term debt instruments. Hence, proponents of the liquidity premium theory add a risk premium (Rp) to the equation expressed above.

$$(2) \text{tR}_L = \sqrt[n]{(1+R_1)(1+r_1)(1+r_2)\dots(1+r_{n-1})} - 1 + R_p$$

In this theory, the yield curve will be upward sloping even if short-term yields are expected to remain constant.

The above two theories assume bonds across various maturities are perfect substitutes for one another.

Under the third theory, the market segmentation theory, the role of expectations in determining term structure is minimized. Instead, supply and demand pressures determined largely by institutional considerations dictate the yield on Treasuries at each particular point on the Treasury curve. Interest rates at each part of the Treasury curve reflect the equilibrium yield necessary to balance supply and demand. If investors desire a highly liquid portfolio, they will prefer short-maturity Treasury bills to longer-term Treasury bonds. Because investors tend to want liquidity in their portfolio and corporate treasurers want to earn yield on their cash holdings but have cash readily available, demand for shorter-maturity bills should usually be greater than demand for longer-term bonds. This demand at the short end drives up the price for Treasury bills and, inversely, moves Treasury bill yields lower. With demand greater for shorter maturity Treasury bills relative to Treasury bonds, the resulting yield curve is typically upward sloping according to this theory. A shortcoming of the market segmentation theory is that the theory fails to explain why interest rates on various maturities tend to rise and fall together.

The last theory, an offshoot of the market expectations theory, is the preferred habitat theory. In this theory, investors have distinct parts of the curve (maturities) in which they prefer to invest. This theory holds that short-term investors who seek liquidity tend to prefer the short part of the Treasury curve. Life insurance companies prefer the longer part of the curve so the maturity on their Treasury bond assets matches the expected maturity or payout of life insurance claims liabilities. Followers of this theory believe short-term investors outweigh long-term investors, at least in dollar terms. Hence, demand for short-term Treasury bills is greater than longer-term Treasury bonds, which creates an upward sloping yield curve. This theory is a hybrid of the expectations theory because it acknowledges that, in spite of distinct maturity preferences, issuers and buyers of debt instruments will deviate from their “preferred maturity habitat” if they expect to profit appreciably by doing so.

The Predictive Power of the Yield Curve: Pre-1992 Studies

The Kessel 1965 Study

In his 1965 seminal study, Rueben Kessel examined yield curve behavior during the twenty-six business cycles between June 1857 and February 1961 as defined by the National Bureau of Economic Research.^{3,4} Because of various exogenous factors affecting debt instrument yields during this extended time period (e.g., tax treatment of Treasuries during certain parts of the time frame, changing supply of Treasuries, etc.), Kessel segmented his research into specific time frames to make results more homogenous. In the early periods, yields on Treasury securities were not complete.

³Kessel, Reuben A, 1965. “The Cyclical Behavior of the Term Structure of Interest Rates.” NBER, *Occasional Paper no. 91*.

⁴ <http://www.nber.org/cycles.html>

For the period between June 1857 and December 1914, a period marked by fifteen business cycles, Kessel calculated the yield spread between short-term and long-term interest rates using average call money rates (short-term rate proxy) and average railroad bond yields (long-term bond proxy). Kessel's use of these particular proxies is not optimal. However, marketable public debt was virtually non-existent until the First World War. On average, during the 1857-1914 period, short-term interest rates were highest at each peak of the economic cycle (varying between seven and eight percent) and lowest at each trough (yielding between three and four percent). Longer-term railroad bond yields remained more stable during each business cycle (yielding between four and five percent). Examining the relationship between the short and long-term debt instruments, Kessel determined that, on average, the yield curve was most positively sloping at the beginning of economic expansions and most negatively sloped at the peak of economic cycles. Short-term rates started to decline at the beginning of economic contraction before leveling off and then rising again at the start of economic expansion. Again, longer-term railroad bond yields remained relatively stable.

For the economic period between December 1914 and March 1919, Kessel provided no particular discussion or charts on yield curve behavior. Perhaps Kessel determined that too many exogenous distortions were present, thus skewing debt issuance and yields during the First World War.

Between January 1920 and March 1933 four recessions occurred. For this period, Kessel provided a graph plotting the yields of long-term government securities against three-to-six month Treasury notes and certificates. The author noted the use of three-to-six month Treasury notes and certificates prior to 1931 due to spotty issuance of Treasury bills before 1929. He did not disclose the maturity that he employed for longer-term government securities.

Between January 1920 and March 1933, there were two times when the yield curve inverted. The first was between June 1920 and March 1921 and the other between January 1928 and November 1929. The first period's inversion occurred during the January 1920-July 1921 recession. Hence, prior to this recession the yield curve was late in its forecast (assuming the recession dating was correct). The second inversion began nearly twenty months before the start of the August 1929-March 1933 Great Depression. However, the peak of the inversion, where the yield gap was greatest, occurred just a few months prior to the start of the Great Depression. No inversion occurred prior to the May 1923-July 1924 recession or the October 1926-November 1927 recession. However, starting in late 1922, just prior to the May 1923-July 1924 recession, the yield curve began to flatten, with the short-term proxy yield closing the distance between itself and the long-term proxy (though the yields were never equal). The same occurred prior to the October 1926-November 1927 recession. Beginning in early 1924, the short-term yield began increasing sharply, closing the gap between itself and the more stable yield of the long-term bond. The spread became smallest (hence, the yield curve became most flattened) just at the start of the October 1926-November 1927 recession.

Kessel made the decision to segregate the 1920-1933 time frame from the post-Second World War period. Besides the aforementioned reasoning given for using non-Treasury bill yields as a short-term yield proxy prior to 1931, prior to the Second World War most long-term government debt was partially tax exempt while short-term debt was fully exempt from taxes. Kessel believed that the favorable tax treatment given to government debt prior to the Second World War could skew comparability with post-World War I Treasuries, which did not receive the same tax treatment.

A separate graph was included for the period between 1934 and 1941. During this prewar period, one recession occurred, extending from May 1937 to June 1938. No inversion of the yield curve occurred. Despite the pre-war research and findings, Kessel states that between 1921 and 1945 the relationship between inverted yield curves and recessions was weak, at best.

After 1945, Treasury yield data were more consistent, as short and long-term Treasury issuance was robust with uniform tax treatment of interest from short-term and long-term Treasuries. Hence, the majority of his analysis focuses on the postwar period extending from October 1945 to February 1961.

In exploring Treasury yield curve behavior during the four post-war business cycles prior to early 1961, Kessel examined three-month, nine-to-twelve month, three-to-five year, and twenty-year bond yield behavior. During this four-cycle period Kessel discovered there were distinct movements in interest rates coinciding with economic cycles, wherein the high and low points of shorter-term interest rates were closely related to peaks and troughs of business cycles, respectively. Particularly noted is that the volatility of short-term rates was much greater than the volatility of long-term or twenty-year government rates (which was also the case pre-1945 when long-term bond yields were relatively stable).

Kessel noted that the average change in short-term or three-month Treasury bill yields during each business cycle from trough to peak was positive 1.73 percentage points while the average change in long-term Treasury rates in the four business cycle troughs to peaks was a lesser positive 0.86 percentage point. From trough to peak, the short-term yield volatility was greater than that of long-term Treasuries. On the other end of the cycle, from the economic cycle peak to trough, short-term yield declined 1.24 percentage points while longer-term yields declined a lesser 0.44 percentage point. From the peak of the economic cycle, when short-term

rates were highest, to the trough, short-term rates declined more than long-term rates. In intermediate maturities, the nine-to-twelve month Treasuries and three-to-five year Treasuries moved in similar degree as the three-month Treasury.

Specific to recessions, Kessel's research found that short-term yields failed to rise above twenty-year Treasuries prior to the first two post-war economic recessions beginning in November 1948 and July 1953. However, at the beginning of the last two recessions, Kessel found that in August 1957 and April 1960, the nine-to-twelve month yield rose above the twenty-year Treasury yield, even though the three-month yield did not. The yield curve inversion between the nine-to-twelve month Treasury and twenty-year Treasury formed less than a year before the two economic downturns.

Kessel did not provide a hypothesis explaining why the three-month Treasury yield did not increase above the twenty-year Treasury yield or why the aforementioned yield curve inversion began just prior to the 1957 recession, leaving this discovery to future research.

The Laurent 1988 Study

Robert Laurent studied the ability of certain monetary policy levers to influence future changes in real national income or GNP.⁵ Laurent stated that prior to his published research little was understood about the accuracy of Federal Reserve policy in promoting maximum sustainable output while controlling inflation. Laurent noted that before 1980, changes in money were considered to have a direct and predictable impact on the level of nominal GDP. After 1980, the relationship appeared to have broken down, as the velocity of money became highly unstable.

To judge the success of the Federal Reserve's policies in achieving its goals, Laurent employed ordinary least squares regressions to test the relationship between four independent

⁵ Robert D. Laurent, 1988. "An interest rate-based indicator of monetary policy." *Economic Perspectives*, Federal Reserve Bank of Chicago, issue January: 3-14.

monetary levers and the quarterly percentage change in GNP, annualized. The four independent variables tested included (1) the federal funds rate, on a bond equivalent basis, (2) the real federal funds rate (the federal funds rate less the annual rate of change in the GNP price deflator over the past four quarters), (3) the change in real M2 (defined as the annualized quarterly percentage change in M2 minus the annualized quarterly change in the consumer price index or CPI) and (4) the yield spread (defined as the long-term bond yield less the federal funds rate).

The federal funds rate is the overnight interest rate banks with excess cash reserves held at the Federal Reserve charge borrowing banks. The Federal Reserve currently targets the federal funds rate level through open market operations. If the Federal Reserve wishes the federal funds rate to decline it will purchase Treasuries from dealers, thus increasing excess reserves in the banking system. With access to reserves now at lower interest rates, banks are in a position to expand their loans. Banks loan rates decline. With the increased lending, GNP is likely to be stimulated through increased consumption and investment expenditures. The reverse effect on the economy typically occurs should the Federal Reserve want to slow economic activity by selling securities to dealers, thus draining funds from banks and forcing them to tighten lending standards. The cost for banks to borrow from one another increases as the federal funds rate increases. This translates into reduced lending and, in turn, slower money growth and declining aggregate demand for goods and services.

Economists have argued that the true cost of banks borrowing from one another is not the nominal but the real federal funds rate. This is because when banks lend out money, it is at a rate that accounts for expected future inflation. Banks do not want to be repaid in depreciated dollars, unless compensated fully for expected inflation. Hence, to reflect the actual impact of

the Federal Reserve's policies via the change in federal funds target rate, the fed funds rate needs to be adjusted for inflation to arrive at the real cost of bank lending to one another.

Real M2, as previously defined, was the third monetary lever tested. Laurent did not state why different price deflators adjusted the nominal federal funds rate and M2. Regardless, adjusting for inflation, when growth in the real money stock declines the result should eventually be lower economic activity; higher real money growth is expected to lead to expanded economic activity. Laurent argues that the post-1980 breakdown in the relationship between M2 and nominal GDP resulted from the deregulation of interest rates paid on bank deposits.⁶ With interest rates now payable on deposits, the public increased its deposits relative to income. Hence, this deregulation lowered velocity of M2. As a result, M2 significantly increased (without a significant decline in fed funds rate). This resulted in erroneous predictions of future real economic growth based on economic forecasting models using M2.

The fourth independent variable Laurent tested against GNP changes was the spread between the twenty-year constant maturity Treasury bond rate and the federal funds rate (annualized). The twenty-year rate was used as the long bond proxy because it was the longest consistently quoted Treasury bond rate at the time of Laurent's study. The federal funds rate is accurately controlled by the Federal Reserve when it is targeting that rate. If the spread turned out to be a good predictor of GNP change, Laurent felt the Federal Reserve Board could control economic growth via targeting not the fed fund target but the spread. By focusing on the spread and not actual levels of rates, the Federal Reserve could successfully control economic growth, in this view.

⁶ The *Depository Institutions Deregulation and Monetary Control Act of 1980* implemented a phase-out of interest rate ceilings payable by banks on various types of deposits, to be complete by 1986.

Laurent first plotted each of the four independent factors against the level of real GNP, and found that each of the factors was correlated with real GDP movements. To determine the predictive performance of each factor, Laurent utilizes an ordinary least squares regression-based model. Citing “wide agreement” that changes in monetary factors lead changes in GNP by six to nine months, Laurent independently tested each factor lagged from one to eight quarters (eight independent variables with one intercept representing the ninth quarter) against the quarterly change in real GNP. No model illustration was provided within the research article.

Running regressions with each of the four independent factors, lagged from one to eight months, against the quarterly change in real GNP (annualized) from 1961:Q2 through 1986:Q4, test results were generated which provided estimations of which factor and related lag was superior in predicting changes in real GNP.

For the 1961 through 1986 test period, the superior explanatory factor was determined to be the level of federal funds rate, which exhibited the lowest RMSE and highest adjusted R^2 . The spread factor came in second, followed by the real M2, then the real federal funds rate.

As Laurent admits, a problem with the above is that the regression is run assuming the quarterly GNP is known at the same time the spread is known. GNP is reported with at least a one-month lag, with revisions up to three months (not including five-year revisions). However, independent factors are observable at the end of each month. For the model to be useful, one needs to regress the independent factors against the real GNP value available at the time the independent factors’ values are known.

With that, Laurent regressed eight quarters of lagged factors against real GNP one quarter prior. Laurent used stepwise regression analysis, testing each lagged variable separately against real GNP. The test period was adjusted to include 1964:Q1 through 1986:Q4. For the out-of-

sample test, the superior independent factor which had the lowest root mean square deviation or RMSE was the one-quarter lagged spread factor with a RMSE of 3.6 percent, followed by the level of nominal federal funds rate, percentage change in real M2 then, lastly, the level of the real federal funds rate. The only change in the order of effectiveness was between the spread variable and level of nominal federal funds rate.

Laurent reports that the above exercise is not without issues. The model used is a simple regression model. A non-linear relationship may exist between the variables and real GNP. Secondly, even with the spread model with a one-quarter lag best at predicting the change in real GNP, a resulting large root mean square error of 3.6 percent hardly makes the model useful in trying to influence real income via changes in the short-term part of the spread curve by changing the federal funds rate.

According to Laurent, what the results show is that controlling the federal funds rate (and, in turn, the spread between the fed funds rate and twenty-year Treasury) proves a better and easier tool to control real GNP growth than trying to adjust M2.

The Harvey 1989 Study

Campbell Harvey's research compared the information available in the bond market versus the stock market in forecasting real economic changes.⁷ Drawing on the theory of marginal rate of substitution, Harvey believed current asset prices should reflect expectations about future business cycles. Harvey defines the marginal rate of substitution as "the intensity at which people are trading today's consumption for tomorrow's consumption". That is, if investors believe there is a strong likelihood for an economic downturn, investors will want to simultaneously buy long-term bonds and sell short short-term bonds. Short-dated bonds have

⁷ Campbell R. Harvey, 1989. "Forecasts of Economic Growth from the Bond and Stock Markets." *Financial Analysts Journal*, Vol. 45, No. 5: 38-45.

less duration so price volatility is lower. Hence, prospective price appreciation is lower than for longer-term bonds. Hence, the substitution if investors believe interest rates will decline.

In the above scenario, increased selling of short-term bonds will drive their yields up while increased demand for long-term bonds will drive their yields down. A resulting flattening or inverted yield curve is expected. The author noted the yield curve inverted prior to the latest four recessions prior to the article's publication, including the recessions that began in December 1969, November 1973, January 1980, and July 1981.

The correlation between equity price movement and economic activity is relayed in the fundamental equity price model:

$$(3) \text{ Stock price}_t = \sum_{j=1}^{\infty} \text{Expected Dividend}_{t+j} / (1+k)^j$$

Where:

k is the discount rate for riskiness of dividends; k is usually assumed constant and j is years in the future

According to Harvey, when investors expect an impending economic downturn, they will anticipate either lower dividends resulting from lower earnings, or an increase in the discount rate due to increased market risk. Hence, in either scenario the stock price will drop based on assumptions regarding future economic expectations. In theory, therefore, stock prices should act as a predictor of coming economic recessions just as yield curves should.

The author believes evidence is not kind to the stock market as a predictor of economic downturns, noting, for example, the sharp stock market decline in the fall of 1987, which was followed by solid economic growth during 1988.

In specifying a yield-curve related forecasting model of economic change, Harvey uses a simple regression model:

$$(4) \text{Growth}_{t+1:t+5} = a + b(\text{yield spread})_t + u_{t+5}$$

Where:

$\text{Growth}_{t+1:t+5}$ is annual logarithmic growth in real GNP from quarter $t+1$ to quarter $t+5$

Yield Spread_t is the spread between long-term and short-term annualized yields to maturity at time t ; u is the residual term

a and b are fitted coefficients with a representing the average real GNP growth when the yield spread equals zero, and b representing the percentage increase in growth per each one percent increase in the spread.

Harvey uses two simple regression models for his research to test spreads. To test the forecasting ability of bond spreads, the short-term yield used in both models is the three-month Treasury bill yield. The two models differ with respect to long-term yields with one model using the five-year Treasury yield and the second using the ten-year Treasury yield. The spread equals the logarithm of one plus the long-term Treasury yield divided by one plus the Treasury bill yield (annualized).

To compare the forecasting superiority of the yield spread vis a vis the stock market, Harvey uses two proxies of equity market change. The first is the one-quarter logarithmic growth in the S&P 500 with the other being the annual growth of the S&P 500. Harvey provides no explanation as to why the particular proxies for the short, long-term bond or equity market are used. To use data available at the time of forecast the independent financial variables are lagged one quarter. Using data from 1953:Q2 through 1989:Q2, results show the ten-year spread model

is superior to the five-year spread model and two equity-related models for the entire period tested.

The ten-year forecast model is reported as:

$$(5) \text{Growth}_{t+1:t+5} = .020 + 1.294(\text{Yield spread})_t + u_{t+5}$$

(5.36)(5.76)

Figures in parenthesis are t-statistics. This result indicates that each one percentage point increase in the yield spread was associated with more than a one percent increase in the forthcoming growth rate.

The ten-year model produced an R^2 of 0.32 compared to an R^2 of 0.30 for the five-year model, 0.045 for the one-quarter stock return and minus 0.004 for the four-quarter stock return model. The slope coefficient for the four-quarter model was not statistically significant.

After separating and regressing the time period between 1966:Q1-1989:Q2, and 1976:Q1-1989:Q2, to test for changes in the relationships, the order of model success did not change with the ten-year spread model dominating the other three models with the R^2 of 0.40 for the 1966:Q1-1989:Q2 period and 0.45 for the 1976:Q1-1989:Q2 period with all coefficients statistically significant. Given the results, Harvey's research shows that in using a simple regression model the one quarter lagged ten-year/three-month spread was fairly good in predicting changes in real GNP, and improved in the more recent time period.

The Estrella and Hardouvelis 1991 Study

Shortly after the July 1990-March 1991 recession, then Fed Bank of New York economists Arturo Estrella and Gikas Hardouvelis published their research findings on the success of the term structure or yield curve in predicting real economic activity. Their research was multifold in that they tested the yield spreads' ability to predict cumulative and marginal changes in real economic activity using linear regression models, and they also used a non-linear

probit model to determine if yield curve spreads predicted economic recessions, as defined by the National Bureau of Economic Research (NBER).⁸

Using data from 1955:Q1 through 1988:Q4, their first pursuit was to determine the relationship between yield spreads and the cumulative change in economic activity. The latter was specified as the dependent variable, defined as the annualized cumulative percentage point change in the seasonally-adjusted, final-revised real GNP, based on 1982 dollars. The dependent variable was calculated as

$$(6) Y_{t,t+k} = (400/k) / [\log(y_{t+k}/y_t)]$$

Where:

$Y_{t,t+k}$ is the annualized GNP percentage change from the current quarter t to future quarter $t+k$

k is the forecasting horizon in quarters.

y_{t+k} is the level of real GNP during quarter $t+k$

For the independent yield spread variable, the authors calculated the difference between the average quarterly bond equivalent yields of the ten-year Treasury bond (R^L) and three-month Treasury bill (R^S), annualized. The independent variable, or slope, is defined as:

$$(7) SPREAD_t = R^L_t - R^S_t$$

⁸ Arturo Estrella and Hardouvelis, Gikas A, 1991. "The Term Structure as a Predictor of Real Economic Activity." *Journal of Finance*, American Finance Association, vol. 46(2): 555-76.

In using average quarterly yield data versus point-in-time Treasury yields, the authors noted earlier research by Park and Reinganum that discovered systematic biases in first-of-month bond yields.⁹

Combined, the estimated cumulative change model is:

$$(8) (400/k)(\log y_{t+k} - \log y_t) = \alpha_0 + \alpha_1 \text{Spread}_t + e_t$$

Using the quarterly sample between 1955:Q2 and 1988:Q4, the regression was run for one through twenty forecasting horizons. Test results show the six quarter lagged spread provided the best forecast for the cumulative change in GNP, with an R^2 of 0.38 and lowest standard error estimate (SEE) of 1.70. The model is estimated as:

$$(9) Y_{t,t+k} = 1.89 \times 1.15 \text{Spread}$$

Standard errors: (0.48) (.22)

The authors noted that the standard errors are Newey and West corrected standard errors which account for conditional heteroscedasticity and the moving average created from the overlapping forecasting horizons.

In their study, Estrella and Hardouvelis also tested the ability of the yield spread to predict future marginal percent changes in real GNP from quarter $t+k-j$ to quarter $t+k$, defined as:

$$(10) Y_{t+k-j,t+k} = (400/j) [\log(y_{t+k}/y_{t+k-j})]$$

Where:

y_{t+k} is the level of real GNP of quarter $t+k$

k is the forecast horizon

⁹Park, Sang Y. and Marc R. Reinganum. "The Puzzling Price Behavior of Treasury Bills that Mature at the Turn of Calendar Months." *Journal of Financial Economics*, June 1986, 16: 267-83.

j equals 1 for forecasting horizons 1 through 8 and equals 4 for forecasting horizons 12, 16 and 20

The model to be estimated for marginal change is:

$$(11) \quad Y_{t+k-j,t+k} = \beta_0 + \beta_1 \text{Spread}_t + u_t, \text{ and } j \text{ is } 1 \text{ or } 4$$

Estrella and Hardouvelis noted that results from the marginal changes regression could be utilized to estimate how negative the spread would need to go to predict a recession (using the often-used definition of two consecutive declines in quarterly GNP). To illustrate, a portion of the regression results is presented in Table 1 below along with calculated “breakeven yields” which equate to how negative a spread would have to be to signal a forthcoming recession.

Table 1: Marginal Change Estimated Coefficients and Recession Breakeven Yields

K	α_0	β_1	R ²	SEE	B/E Yld
1	1.74 (0.64)	1.23 (0.29)	0.13	3.75	-1.41
2	1.51 (0.58)	1.46 (0.31)	0.18	3.64	-1.03
3	1.67 (0.54)	1.3 (0.30)	0.14	3.75	-1.28
4	1.89 (0.53)	1.09 (0.30)	0.09	3.86	-1.73

To interpret, a negative 1.41 percent spread is necessary to be associated with negative growth from quarter t to quarter t+1, on average. For quarter t+1 to t+2, a negative 1.03 percent spread would be needed. For quarter t+2 to t+3, a negative 1.28 percent spread would be necessary.

By plotting, Estrella and Hardouvelis observed periods of low correlation between the four-quarter lagged spread and real GNP output; the authors hypothesized that the yield curve might best be used as a predictor of significant changes in economic output such as a recession. In this effort, the authors constructed a binary probit model to test their hypothesis. The model they used was:

$$(12) \quad \Pr[X_t=1|\text{SPREAD}_{t-4}] = F(\alpha + \beta \text{SPREAD}_{t-4})$$

Where:

Pr is the probability

F is the cumulative normal distribution

X_t equals unity during periods dated as official recessions by NBER .

The above is a probit model with a log-likelihood function of:

$$(13) \quad \text{Log } L = \sum_{xt=1} \log F(\alpha + \beta \text{SPREAD}_{t-4}) + \sum_{xt=0} \log F(1 - \alpha + \beta \text{SPREAD}_{t-4})$$

Maximizing the above equation with respect to the unknown parameters α and β over a quarterly sample period from 1956:Q1 through 1988:Q4 leads to:

$$(14) \quad \Pr[X_t=1|\text{Spread}_{t-4}] = F(-0.56 - 0.78\text{SPREAD}_{t-4})$$

standard errors: (0.16) (0.16)

The Pseudo- R^2 equaled 0.297.

This equation implies that an increase in the spread between long and short-term rates reduces the probability of a recession and vice versa. Despite the coefficients determined to be statistically significant, the authors noted that when using a non-linear model, evaluating the

quantitative significance of the relationship between recessions and spread can be difficult.

Therefore, the authors plotted the estimated probability calculated from the four-quarter lagged spreads during the tested period.

Within their graph, they demarcated the time frames defined as recession. Combined, they determined whether the probability of a recession, lagged four quarters, increased prior to a recession occurring. They found that peaks in the probability plot were associated with recessions during the test period, except during the 1966-1967 period when a 40 percent probability was generated, followed only by an economic slowdown and not a dated recession. The peaks in the recession probability plot often occurred during recessions, not the start of them, so using a reduced spread lag might have produced better results. However, I also observed that the probability plot did increase prior to official recessions. Finally, what the authors do not note is that the sharp decline in probability could also be used to anticipate a recession's end, which would be useful in the formulation of policy and investment decision-making.¹⁰

The Predictive Power of the Yield Curve: Post 1992 Studies

The Estrella and Mishkin 1996 Study

Arturo Estrella and Fredrick Mishkin's study tested the usefulness of the yield curve for forecasting recessions against three other financial variables commonly used in predicting economic inflection points.¹¹ These variables included stock prices, the Conference Board's

¹⁰ The New York Federal Reserve provides a chart indicating the probability of recession on its website http://www.newyorkfed.org/research/capital_markets/Prob_Rec.pdf

¹¹ Arturo Estrella and Frederic S. Mishkin, 1996. "Predicting U.S. recessions: financial variables as leading indicators." *Research Paper 9609*, Federal Reserve Bank of New York.

index of leading indicators, and the alternative Stock and Watson index of leading indicators.

Estrella and Mishkin noted that researchers earlier tested the yield curve's performance.

However, the authors' research differs in that they focused on simply predicting recessions rather than attempting to create a point-specific model of future economic change. Additionally, the authors note that their research quantifies the out-of-sample model success versus the less useful in-sample performance, making their research more useful in the working environment.

In estimating the probability of a recession, they draw on the use of a probit-type regression model that Estrella used in earlier reviewed research. Though the model specifications were not given in their research publication, reference to an earlier publication allowed inference of the model's specification, which is presented below.

The probit model is specified as:

$$(15) \quad P(R_{t+k}=1) = F(\alpha_0 + \alpha_1 X_t)$$

Where:

R_t is 1 if the U.S. economy is in a recession in quarter $t+k$, as defined by the National Bureau of Economic Research, or is 0 otherwise.

k is the number of quarters ahead that R_t will be 1 or 0.

α is the intercept or constant term

F is the normal cumulative distribution function (the normal cumulative distribution function F within the model allows the sum of $\alpha_0 + \alpha_1 X_t$ to be converted into a probability that a recession will occur at quarter $t+k$).

X_t is the explanatory variable (yield curve, stock price, the Conference Board's index of leading indicators and the alternative Stock and Watson index of leading indicators).

Because Estrella and Mishkin were comparing the success of the yield curve spread against the three aforementioned financial variables, the X_{1t} used:

- (1) the yield spread defined as the average quarterly spread between the ten-year Treasury and three-month Treasury bill, both on a bond-equivalent yield basis,
- (2) the NYSE stock returns, defined as the quarterly percentage point change in the New York Stock Exchange index,
- (3) the Conference Board's index of leading indicators (LEI) as measured by the quarterly percentage point change in the LEI, or
- (4) the Stock-Watson leading economic indicator index measured by its quarterly percentage point change.

The period used for testing includes 1960:Q1 through 1995:Q1. This period covers six recessions as dated by the NBER.

When the regression was run using the spread variable, the following equation was reported:

$$(16) \quad P(R_{t+4} = 1) = F(-0.66 - 0.81\text{Spread}_t)$$

t-stat: (n/a) (-4.99)

If the average spread at quarter t (Spread_t) averaged 0.76 percent, the estimated probability of a recession four quarters from now is ten percent, as indicated in the normal cumulative probability table.

The model was run sixteen separate times with each of the four variables being lagged four separate quarterly periods (one quarter, two quarters, four quarters and six quarters). No table of results was provided in the published article. However, the authors provided separate graphs plotting the results of each test with the years in the study plotted on the x-axis and

probability percent plotted on the y-axis. NBER recessions were identified by shading of time periods. The results showed that none of the independent variables signaled a 100 percent probability of a recession just prior to a recession occurring. However, the authors do not discredit their model, noting that in normal economic periods a probability of around ten percent is typical, and any deviation from that finding is notable.

For the one-quarter leading forecast, the authors note the leading economic indicator indices, particularly the Stock-Watson leading index, provided the best forecast before each recession. For two or more quarters, the yield curve proved superior to the other financial variables and its superiority increased the further out the forecast went.

Specifically, for the one quarter prior to the start of a recession, the leading economic indicator index, and the Stock-Watson index more so, were better at predicting the start of the recessions that started in November 1973, January 1980, and July 1981. However, the LEI gave false recession signals (elevated probabilities) during the 1982 to 1990 economic expansion. The Stock-Watson index completely missed forecasting the recession that started in July 1990. The yield curve and NYSE stock variable were less accurate in predicting the earlier recessions but superior in signaling the recession that commenced in July 1990. Beyond one quarter, the yield curve proved superior to the other tested variables.

Estrella and Mishkin hypothesized that the yield curve may have produced a higher recession probability signal before the earlier recessions because the Federal Reserve likely induced the earlier recessions through restrictive monetary policy, which forced short-term yields up and reduced the yield spread. The Fed played a lesser role in the July 1990 to March 1991 recession which was triggered by an exogenous decline in consumer confidence following the occupation of Saddam Hussein's forces in Kuwait. Additionally, the authors note that the yield

curve was less volatile during the 1990s, so the probability of a flattening or inverted yield curve lessened.

Estrella and Mishkin noted that the results demonstrated the yield curve could be a simple and useful forecaster of recessions over longer lead times, which is of particular interest to policy makers. In addition, the yield spread is very easy to calculate. It is a simpler way to forecast recessions than more elaborate models. If more elaborate models are used, the results of these models could be compared to the simpler yield curve model. If the more sophisticated model's recession forecast agrees with the yield curve's inference, then the user's confidence about an impending recession may be heightened. If the two models do not agree, the authors state that their simpler model provides a red flag, alerting forecasters to check the specifications of the more sophisticated model. Clearly, the authors show bias in favor of the simpler yield curve model.

The Haubrich and Dombrosky 1996 Study

Also in 1996, Joseph Haubrich and Ann Dombrosky published their research evaluating the ability of the yield curve to forecast recessions and to determine if the relationship changed over time.¹² In this effort, Haubrich and Dombrosky used a simple linear regression model, purposely avoiding nonlinear specifications. In determining their proxies for calculating the yield spread, they decided to remain consistent with earlier researchers. They chose to use the ten-year constant maturity Treasury (CMT) rate and three-month Treasury bill rate traded on the secondary market, converting the Treasury bill rate to a bond equivalent yield. The authors

¹² Joseph G. Haubrich and Ann M. Dombrosky, 1996. "Predicting real growth using the yield curve." *Federal Reserve Bank of Cleveland Economic Review* 32: 26-35.

stated they could have tested other spreads but “trying every single spread would produce something that looked like a good predictor, but it could very likely be a statistical fluke.” In keeping with Estrella and Hardouvelis’ research, the authors used quarterly spread averages to eliminate anomalous yields likely found at the beginning of months. For real economic growth, the authors used the four-quarter percentage point change in real GDP. The time period studied began at 1961:Q1 and ended at 1995:Q3. No specific reason is provided for using this period but the authors note that during this period inflation ranged from one percent per year to thirteen percent, the period included periods of monetary tightening and easing with federal funds rates ranging from under three percent to over nineteen percent, and included five recessions.

A simple regression model was specified as:

$$(17) \quad [\text{RGDP}_{t+4} - \text{RGDP}_t] / \text{RGDP}_t = \alpha + \beta \text{spread}_t$$

Where:

RGDP_{t+4} is the real GDP four quarters ahead

RGDP_t is the real GDP in the current quarter

spread_t is the difference between the ten-year CMT Treasury bond yield and three-month Treasury yield, on a bond-equivalent basis.

In essence, the model used a four-quarter lagged spread to forecast current GDP growth.

The result of the regression was:

$$(18) \quad \begin{array}{l} \text{RGDP Growth}_{t+4} = 1.8399 + .9791 \text{ spread}_t \\ \text{t-stat:} \quad (3.89) \quad (4.50) \end{array}$$

The results of the model produce an R^2 of 0.291. The t-statistics are cited in parentheses. The slope coefficient of 0.9791 indicates an almost one-for-one relationship between the spread

and real GDP growth four quarters in the future. The model indicates that a one percent yield spread equates to a 2.8 percentage point four-quarter-ahead expected increase in real GDP and nearly a two percent negative spread would be required for negative economic growth, given the constant term of 1.84 percent.

The authors stated that using the above specification the coefficients and model results may not be useful in forecasting recessions in real time because the regression is run using spread data available daily against the four quarter change in GDP, which final calculation is not available until three-months after the end of the quarter.

To adjust the model, the regression was run again with the quarterly percentage change in real GDP regressed against spreads available at the time of publishing GDP. To illustrate, the four-quarter growth rate of RGDP for 1979:Q4 is based on spread data from 1961:Q1 through 1978:Q3, rather than 1978:Q4 as was in the in-sample regression. Though the revised model results were not published, the authors stated that the out-of-sample results were “broadly similar” to that of the in-sample model. They reported a 2.04 root mean square error (RMSE) for the in-sample model and a RMSE of 2.10 for the out-of-sample model.

In regressing different sub-time periods between 1961 and 1995, the authors determined that the predictive power of the yield curve changed. From regressing the data of the earliest five-year period (20 data points), the slope coefficient equaled negative 0.14 and was statistically insignificant. For the first half of the period, the slope coefficient was 1.48. For the period between 1985:Q3 and 1995:Q3, the RMSE of 1.07 was calculated for the in-sample model and 2.09 for the out-of-sample model. Both were less than the RMSE calculated for the entire period under study.

The authors hypothesized that the evolving relationship between yield curve spreads and real GDP growth was likely due to the way the yield curve adjusted to new information or even shifts in Federal Reserve policy though they did not provide specific examples.

To further test for a changing relationship between spreads and forthcoming real GDP growth, the authors ran correlations between the two using two different spread lags and different periods. For the period between 1960 and 1995, the correlation between the four-quarter lagged spread and GDP growth totaled 0.54 while the correlation between 1960 and 1985 totaled 0.67. Over the last ten-year time period studied, 1985 to 1995, the correlation is strongest when using a six-quarter lagged yield spread and totaled 0.74. What this implies is that the four-quarter lag spread became less effective in predicting changes in real GDP. By increasing the lagged period to six quarters, from four, a stronger correlation between spreads and real GDP changes was produced.

In the period researched, it appears the yield curve remained a strong predictor of real GDP changes. However, the impact of spread changes on real GDP was delayed more in latter periods.

The Dueker 1997 Study

In 1997, Michael Dueker published a study on the predictive power of yield curves in forecasting U.S. recessions and also the potential for yield curves to predict the duration of recessions.¹³ Dueker wrote that yield curves should normally be positively sloped, even if short-term rates are expected to remain constant at current levels in the future, given investors' need for a risk premium to compensate for an incorrect forecast. However, if investors believe a recession is forthcoming, they will expect monetary policy to become accommodative with the

¹³Michael J. Dueker, 1997, "Strengthening the case for the yield curve of U.S. recessions." *Federal Reserve Bank of St. Louis Review* 79: 41-51.

Federal Reserve reducing future short-term rates. Lower nominal rates also may reflect low real rates of return expected during recessions. According to Dueker, the severity and duration of an anticipated recession will shape the yield curve by influencing the expected magnitude of short-term rate declines. Farther out on the yield curve, Dueker hypothesizes that “rates of different maturities will decline by different amounts, depending on how much their repayment (in present value terms) will take place during the period of low interest rates.”

Provided is an example using a hypothetical seven-year Treasury bond. If investors expect short-term rates to move lower over the next several years (reflecting expectation of recession duration), the seven-year yield should decline. If not, the expected holding period return over the next seven years would be greater for those who held long-term bonds compared to those investors who held a succession of short-term bonds over the same time period, hence violating the expectation theory. Dueker noted and graphically illustrated the inversion of the three-month/thirty-year yield curve prior to the five recessions occurring between 1960 and 1995, which validates his assumption. However, Dueker states that yield curves do not have to invert to forecast a recession, but simply flatten relative to their normal shape. That is, long-term yields would only need to decline relative to short-term yields if investors anticipate lower short-term yields in the future.

The remainder of Dueker’s research focused on using three quantitative models to compare the yield curve’s success rate as a leading indicator for recessions and time duration against other potential predicting factors, including the percentage change in the Standard and Poor’s equity index, real M2 growth, and the yield spread between six-month commercial paper and six-month Treasury bills. He examines the success rate of the yield spread compression at

four time intervals: three months prior to recession, six months prior, nine months prior, and twelve months prior.

Drawing from earlier research of Estrella, Dueker used a probit model to predict a recession dummy variable change.

$$(19) \quad \text{Prob}(R_t=1) = F(c_0+c_1X_{t-k})$$

Where:

R_t equals 1 if a recession is occurring at time t and R_t equals 0 when no recession is occurring at time t .

F is the cumulative standard normal density function

X is the set of explanatory variables used to forecast recessions

To measure the yield spread variable, Dueker used the difference in monthly yields between the thirty-year Treasury and three-month Treasury bills, reported from January 1959 through May 1995 (437 observations). For the binary recession variable, Dueker used the recession dates provided by the National Bureau of Economic Research (NBER). What is puzzling in his report is that thirty-year Treasuries were not regularly auctioned until 1977. Before 1971, twenty-year Treasury bonds were common in refunding operations. From 1971 through 1974, twenty-five year Treasuries were used. I assume he used these as his long-term bond proxies through 1974.

Running his first model, Dueker found the yield curve spread superior to the other potential financial variables for predicting recessions beyond a three-month horizon. Dueker believed the reason for this lies in the fact that long-term yields must decline well before anticipated recessions in order for investors to equalize holding period returns during a recession

and the ensuing recovery. His results showed that the yield curve best predicted a recession nine-months prior to its start.

Using the basic probit model, Dueker found that prior to each recession the estimated probability of a recession did not increase above fifty percent. Also, the duration of a recession was not predicted with any reliability, with the probability prediction declining during the lengthy 1981-1982 recession period.

In a second model, Dueker added a lagged dependent variable (R) to the basic probit model to remove potential serial correlation. The second model is constructed as:

$$(20) \quad \text{Prob}(R_t=1) = F(c_0+c_1X_{t-k}+c_2R_{t-k})$$

Again, the independent variables used were the yield curve spreads calculated three, six, nine and twelve months before an NBER-declared recession. Dueker found the second model was better at predicting the duration of the recession, though predictive power was still no greater than fifty percent prior to the recessions that began in April 1960, December 1969, the January 1980 through November 1982 double-dip recession period, and July 1990. The final model used was the probit model with Markov switching to provide a stronger test of the ability of the yield curve to predict the start and/or duration of the recessions that occurred between 1960 and 1995.

The author's results show that the yield curve remained superior to the other financial variables tested. Additionally, Dueker stated that the third model was superior to the two earlier models at predicting the duration of recessions and forecasting the beginning of major recessions in November 1973 and lengthy two-recession period from January 1980 through November 1982, but did not predict the milder recessions that began in April 1960, December 1969 and July 1990.

In summary, Dueker's three probit models demonstrated the yield curves' superiority in predicting recessions compared to the other tested financial variables (change in M2, S&P 500 and spread between six-month commercial paper and six-month Treasury bills). The probability calculated before each recession, however, was no greater than fifty percent.

The Boulier and Stekler 2000 Study

Bryan Boulier and H.O. Stekler tested to determine if daily reported Treasury yield curve spreads were useful in predicting higher frequency proxies of the economy.¹⁴ Specifically, the authors used the monthly reported Index of Industrial Production published by the Federal Reserve between April 1953 and January 1998 as their economic activity proxy.

To determine the success of the yield curve in forecasting macroeconomic activity, the authors used regression analysis and reported the following estimated equation, developed from the complete time series:

$$(21) \quad \text{RIP}_{t,t-12} = .0685 + 1.928 \text{ SPREAD}_{t-12}; R^2 = 0.18$$

standard errors: (0.325) (0.182)

Where:

$\text{RIP}_{t,t-12}$ is the percentage point growth rate of the monthly Index of Industrial Production from month t-12 to month t.

SPREAD_{t-12} is the spread between the ten-year Treasury bond yield and three-month Treasury bill yield at time t-12

The authors also tested whether the regression was robust in different time sets by using recursive regressions and the one-step Chow test. The Chow test indicated a structural break

¹⁴ Bryan Boulier and H.O. Stekler, 2000. "The term spread as a monthly cyclical indicator: an evaluation." *Economic Letters* 66: 79-83.

beginning January 1984 (using spreads in January 1983). Accordingly, the authors ran two regressions using the same form of equation, as above, but breaking the data into intervals encompassing December 1954 to December 1983 and January 1984 to January 1998. The following two regressions results were produced:

$$(22) \quad \text{RIP}_{t,t-12} = .0209 + 3.290 \text{ SPREAD}_{t-12}; R^2 = 0.30 \text{ (time period =1954.4-1983.12)}$$

(0.373) (0.265)

and

$$(23) \quad \text{RIP}_{t,t-12} = 1.364 + 0.843 \text{ SPREAD}_{t-12}; R^2 = 0.08 \text{ (time period =1984.1-1998.1)}$$

(0.522)(0.217)

Results show that the yield spread proved a more powerful predictor of monthly economic growth in the earlier period (standard errors are in parenthesis).

The Wright 2006 Study

Expanding on Estrella's earlier research, Wright used the probit regression model to calculate probabilities of recessions, including the recession that began in March 2001.¹⁵ Aside from the yield curve, Wright also tested a different set of recession predictors not tested by earlier studies.

Wright acknowledged the validity of earlier research which found the ten-year/three-month Treasury yield curve spread a good predictor of recessions. He cited the importance of his research given that at the time of publication, the yield curve was flat or slightly inverted, depending on the period used in the calculation of the yield spread.

Wright believed the expectations hypothesis accounts for why the yield curve may provide a leading indication of economic downturns, with short-term rates reflecting the Federal

¹⁵ Jonathan H. Wright, 2006. "The Yield Curve and Predicting Recessions." *Federal Reserve Board Working Paper No. 2006-7*.

Reserve's current monetary policy and long-term rates being the average of expected future short-term rates. What the expectations theory ignores is the excess spread along the yield curve not explained by the expectations theory, defined as the term premium. The existence of the term premium can cause distortions in yield curve analysis, Wright reported, because the premium changes over time and typically increases with Treasury maturities. Hence, the yield curve reflects more than just expected changes in future interest rates.

Wright noted that past research gave no attention to whether a decline in the yield spread was due to short-term rates rising or long-term rates declining. By including the federal funds rate as an independent variable in the regression equation, Wright believed the aforementioned issues of term premiums are eliminated. The inclusion would also determine whether the change in the spread of the yield curve was due to a movement in short-term or long-term rates.

In testing recession predictability, several probit regression models were run using four financial variables and three different quarter-period lags (two-quarter, four-quarter and six-quarter). Data were used from 1964:Q1 through 2004:Q4. Wright cited earlier research that discovered potential Treasury price distortions in long bonds prior to 1964. Prior to 1964, a significant proportion of long-dated Treasuries were callable or "flower bonds" which could be redeemed at par before maturity in order to pay estate taxes.

The first financial variable tested was the spread between the three-month and ten-year constant maturity Treasury bonds in the present quarter t , and the lagged two, four and six-quarter horizons or h before the start of NBER-dated recessions. The model is specified as:

$$(24) \quad P(\text{NBER}_{t,t+h} = 1) = F(\beta_0 + \beta_1 \text{Spread}_t)$$

Where:

$\text{NBER}_{t,t+h}$ is the dummy which is 1 during a recession at quarter t to $t+h$ or 0, otherwise

Spread_t^{3m-10Y} is the average spread between the three-month over ten-year constant maturity Treasury term spread

$F(\cdot)$ is the standard normal distribution function

The second model developed extends the above model by adding the level of the nominal federal funds rate (FF_t):

$$(25) \quad P(\text{NBER}_{t,t+h} = 1) = F(\beta_0 + \beta_1 \text{Spread}_t + \beta_2 \text{FF}_t)$$

The third model included both the nominal and real federal funds rate (RF_t) in order to determine whether using the real federal funds rate improves prediction compared to the nominal rate. To derive the real federal funds rate, the nominal rate was adjusted using the log difference in the core PCE price index over the previous four quarters. The model is:

$$(26) \quad P(\text{NBER}_{t,t+h} = 1) = F(\beta_0 + \beta_1 \text{Spread}_t + \beta_2 \text{FF}_t + \beta_3 \text{RF}_t)$$

The final model constructed included an independent variable related to the term premium to determine if the term premium had any usefulness in predicting recessions. In order to incorporate a term premium variable into Wright's model, the author includes a factor developed from earlier research by Cochrane and Piazzesi which proxies the term premium on longer-term bonds with the variable defined as the "return forecasting factor" or RFF_t .¹⁶ The final model is specified as:

$$(27) \quad P(\text{NBER}_{t,t+h} = 1) = F(\beta_0 + \beta_1 \text{Spread}_t^{3m-10Y} + \beta_2 \text{FF}_t + \beta_3 \text{RFF}_t)$$

¹⁶ John Cochrane and Monika Piazzesi, 2005, "Bond Risk Premia." *American Economic Review*, 95: 138-160.

Results from the first model estimate that the yield spread was highly significant for each lag with an R^2 of 0.22 for the two-quarter model and 0.29 for the four and six-quarter models. For the second model, Wright found both the spread and nominal federal funds rate statistically significant. The R^2 measured 0.39 for the two-quarter lag, 0.50 for the four-quarter lag and 0.48 for the six-quarter lagged model. For the third model, where the spread, nominal federal funds rate, and real federal funds rates are included, the author found only the spread and nominal federal funds rate variables statistically significant. The final model included the spread, nominal federal funds rate, and term premium proxy, with the real federal funds rate excluded. Results again show the spread and nominal federal funds rate significant. For the two quarter and four quarter horizon tests, the R^2 was the same as the second and third model, at 0.50. For the six quarter model, the R^2 was slightly higher than the second and third model, measuring 0.50 compared to 0.48. Including the nominal federal funds rate level improved the forecast of recessions for all models tested.

This publication of this research was in February 2006. At the time of publication, Wright noted that the superior second model predicted no recession over the horizon, though the first model predicted a high probability of a recession. As known in hindsight, the recession that started in December 2007, or approximately six quarters after the publication of this research, was one of the most severe in recent history. It is unknown whether the second model after publication forecasted a recession before December 2007. However, it appears that the yield curve remained the most consistent predictor of recessions.

Post-2007 Recession Forecast Studies

The Kucko and Chinn 2007 Study

Published after the latest recession began in December 2007, Kucko and Chinn revisited the predictive power of the yield curve to determine its value for providing policy decision makers an early warning of economic slowdowns.¹⁷ According to the authors, their motivation for conducting research into this subject was prodded by the presence of what ex-Federal Reserve Chairman Alan Greenspan called “the conundrum” or failure of long-term interest rates to increase with short-term interest rates following Federal Reserve rate hikes during the 2004-2007 period. The authors noted potential pressures on long-term interest rates may have resulted from the “Great Moderation” or increase in risk management by financial institutions, greater demand from pension funds for long-term assets (i.e. long-term Treasury bonds), or increased purchases of Treasuries by foreign central banks (e.g., China). In any event, the ten-year/three-month Treasury spread compressed during the 2004-2007 period, when some believed the lack of long-term interest rate volatility was more the result of the aforementioned exogenous forces than forces related to expectations. The authors wanted to understand whether, despite these forces, the yield curve remained a strong predictive power of economic downturns.

In their study, the yield curve measure used to test for predictive power over recessions was the ten-year Treasury yield less the three-month Treasury yield. The authors' reasoning for yield curve inversion prior to economic recessions is aligned with the expectations theory; short-term rates in the future should decline in economic downturns because of lower demand for credit and from monetary easing at the central bank.

¹⁷ Kavan Kucko and Menzie D. Chinn, 2010, "The Predictive Power of the Yield Curve across Countries and Time." *NBER Working Papers 16398*, National Bureau of Economic Research, Inc.

The period of data studied extended from January 1970 through September 2009. As the proxy for economic activity, the authors chose to use industrial production for several reasons. The publishing of industrial production is timely and is reported monthly. The authors also argued that industrial production tracks GDP closely with an estimated correlation of 0.76. Using monthly data also provides a greater sample size, given more frequent reporting. Finally, the authors argued that industrial production data are not revised as significantly as GDP data. For their test, the authors start with the standard bivariate regression model:

$$(28) \quad \text{IPGrowth}_{t,t+k} = \beta_0 + \beta_1 \text{Spread}_t + \xi_{t+k}$$

Where:

$\text{IPGrowth}_{t,t+k}$ is the annual growth rate over the period t through $t+k$

Spread_t is the ten-year Treasury yield minus the three-month Treasury-bill yield at time t

With the above model, the yield spread at time t predicts the annual growth rate of industrial production from month t to month $t+k$. Hence, the authors examine the association between the Treasury spread at time t and the growth rate of industrial production one year and two years ahead where k equals twelve and twenty-four months. The authors note that since overlapping data points occur in testing, due to adjacent year over year industrial production growth figures, the error terms will be serial correlated. The authors account for this using heteroscedasticity and serial correlation robust standard errors. The authors note that unit root tests show that the spreads and industrial production changes are stationary.

The first regression uses the yield curve data set from January 1970 through December 2009. Test results show that in using the one-year lead, a 1.630 slope coefficient was estimated, and was statistically significant at five percent, with the two-year lead coefficient estimated at

1.456, statistically significant at the five percent level. The R^2 was calculated at 0.25 and 0.28, respectively.

The authors ran the model two more times, segmenting the time period between January 1970 through December 1997 and January 1998 through December 2009 to determine whether prediction strength held for both the earlier and latter time frames. They wrote that the time separation point was arbitrary. However, it is clear that more data points are included in the first set than the second.

Using the 1970-1997 data, regression results showed for the one-year and two-year lead, the spread coefficient is greater than when using the complete 1970-2009 data series. The coefficients were statistically significant at the five percent level. When using only the more recent 1998-2009 data, the coefficients were smaller for both the one- and two-year lead models with only the two-year spread coefficient statically significant. The R^2 is smaller for each reduced period relative to the complete data set, with the R^2 for the 1998-2009 smallest of the three data sets at 0.10. Results suggest the yield spreads predictive power weakened in the recent years.

To better identify the predictive power of yield curves, the authors also conducted an out-of-sample regression exercise. In doing so, they tested each yield curve spread against data available at the time the yield curve was available. For example, to calculate the constant and slope parameters for the model used to forecast industrial production growth from January 1990 to January 1991, the only spread data used in the model was that between January 1970 and December 1989. The authors then re-estimated the regression to find the constant and slope parameters for forecasting industrial production growth from February 1990 through February 1991 by adding yield spread data from January 1990.

As the authors explained, recursive regressions were used to construct and plot a series of fitted output for annual industrial production growth. Results were compared to the root mean square error and against a naïve forecast RMSE. The naïve forecast used was a simple autoregressive model (AR1) of growth. If the RMSE for the out-of-sample yield curve spread model was less than the AR(1) model, then the yield spread was considered superior in forecasting annual industrial production growth. For the data sample range from January 1970 through September 2009, the RMSE for the yield spread model was marginally higher than the AR(1) model, at 3.66 versus 3.54, respectively. Hence, it was concluded that the yield curve model did not perform any better than the naïve model at the ten percent significance level. Plotting the yield spread model prediction for industrial growth against actual values, significant divergence was reported for the latest recession. The yield curve model failed to predict the sharp decline in industrial production growth starting in 2007.

The authors hypothesize that the poor out-of-sample results may be due to a paradigm shift in the relationship between the yield curve and economic activity over the period studied. To test for changes in the relationship, the authors used the earlier sample runs from January 1970 through December 1979, estimated the regression, and then forecasted industrial production growth. They continued to repeat this process, moving stepwise up one month at a time using a ten-year rolling period. Using the model results, the authors plotted the coefficient estimates and 95% confidence intervals for each ten-year overlapping test from January 1970 through December 1979.

Their plot showed that since 1998, approximately the start of what is referred to as the “global savings glut” when increased savings pushed long-term Treasury rates down, the

coefficients declined.¹⁸ Additionally, the 95% confidence interval widened until 2005. They cite this as confirmation that the relationship between the yield curve and forthcoming economic growth broke down in the last ten to fifteen years.

After 2005, the coefficient began to increase with the associated confidence interval compressing, though still wider than before 1998. The authors did not discuss the recent coefficient increase and the contracting confidence interval, but generally focused only on the relative smaller coefficients and larger confidence interval since 1998.

Their final test of the yield curve followed methodology used earlier by Estrella and other authors, wherein a non-linear probit model was utilized to determine whether the yield spread predicts recession starts rather than point-specific measures of economic activity. For using this model, the authors referenced Wright's 2006 research, in which the probit model worked best after adding the Federal Funds rate as a second independent variable in order to isolate the impact of short-term interest rate increases on yield spread compression from shifts (or the lack thereof) in the long-term Treasury rate. The two models are specified as:

$$(29) \quad \Pr(R_{t+1,t+k} = 1) = F(\beta_0 + \beta_1 \text{Spread}_t)$$

and

$$(30) \quad \Pr(R_{t+1,t+k} = 1) = F(\beta_0 + \beta_1 \text{Spread}_t + \beta_2 3\text{mo}_t)$$

Where:

t is the current time period.

k is the forecast period; the authors chose to use six and twelve month time periods (equivalent to a six month and one year forecast of recessions).

¹⁸ <http://www.federalreserve.gov/boarddocs/speeches/2005/200503102/default.htm>

$F(\dots)$ is the standard normal cumulative distribution function.

$R_{t+1,t+k}$ is 1 if the economy is in a recession between $t+1$ and $t+k$, and 0 if not. The NBER dates are used to define recessions.

$3mo_t$ is the current three-month Treasury bill rate.

The period studied encompassed January 1970 through September 2009. As reflected in the second model above, the three-month Treasury bill rate was used to isolate volatility in short-term interest rates. The authors chose not to use the federal funds rate without providing a reason.

Results show that the yield spread was significant within both the six month and one-year forecasts. However, unlike Wright's results, the added short-term proxy was not statistically significant at either six months or one year. The authors' results additionally show that the goodness of fit is better with the twelve-month model, with an R^2 of 0.28 compared to 0.16 for the six-month model.

The graph provided within their paper plots the probability results using the six-month lead model. The graph showed a jump in the probability of recession before each past recession start, including the most recent. Hence, it appears that the yield spread, though not good at estimating point specific changes in economic growth, remains reliable at forecasting future economic recessions.

The Fernandez and Nikolsko-Rzhevskyy 2011 Study

Fernandez and Nikolsko-Rzhevskyy was the last relevant available published study summarized for this literature review.¹⁹ The authors' research tested the success of the yield

¹⁹ Adriana Z. Fernandez and Alex Nikolsko-Rzhevskyy, 2011. "Forecasting the End of the Global Recession: Did We Miss the Early Signs?" *Staff Papers No. 12*, Federal Reserve Bank of Dallas.

curve spread in forecasting recessions for the time period between January 1991 and March 2009. Acknowledging earlier results by Estrella and Hardouvelis, in which the relationship between the yield spread and economy was found to be strong at the start of recessions, the authors chose the probit regression methodology, used in earlier research, citing its past success in forecasting nine out of the past ten recessions.

A particular feature making their study unique is the extension of the independent variables to include not only the yield spread but also a separate proxy for investor expectations of future economic growth. Acknowledging the validity of the expectations theory of term structure, by including this separate independent variable defined as the expected output gap, the authors segregate the expectations portion of the yield curve from other factors that may influence changes in short-term and long-term interest rates and, in turn, the yield spread. Additionally, their model allows separate lags for the yield curve and output gap to garner information about which time lag for each variable was best in predicting recessions. The model used was:

$$(31) \quad \text{Pr(U.S. Recession)}_{t+h} = F(C, dr_t, dr_{t-1}, dr_{t-6}, dr_{t-12}, dg_t, dg_{t-1}, dg_{t-6}, dg_{t-12})$$

Where:

$\text{Pr(U.S. Recession)}_{t+h}$ is the probability of a recession h months ahead of current time t ; this is a dummy variable equal to 1 if the month is defined as in a recession by the NBER or 0 if not.

C is the constant term.

dr is the monthly difference between ten-year U.S. Treasury yield and three-month certificates of deposit (the authors' proxy for short-term rates) posted by the OECD.

dg is the quarterly output gap, the monthly difference between the one-year ahead and current annualized real GDP rate or:

$$(32) \quad dg_n = (\text{GDP}_{gr})_{n-4} - (\text{GDP}_{gr})_n .$$

To create a consecutive series of data for the annualized quarter-over-quarter real change in GDP, or GDP_{gr} , the authors spline the annualized quarter-over-quarter change in real GDP for the 1984:Q2 through 2008:Q4 period with the annualized *Consensus Forecasts* quarter-over-quarter expected real GDP growth rate for 2009:Q1 through 2009:Q4.²⁰ The authors converted the quarterly series to monthly using a time conversion technique which they stated was to be explained in a forthcoming publication by Levin and Taylor.

Separate models were estimated using different permutations of lags (one, six and twelve months) for the yield spread and output gap variables. The McFadden R-square was calculated for each model, along with values for the Hannan-Quinn (HQ), Akaike (AIC) and Bayesian (BIC) information criterion used for model selection. The latter two provide a penalty to the goodness of fit based on the number of independent variables used in the model, as adding independent variables can cause overfitting, resulting in a high R^2 not necessarily due to a strong goodness of fit.

The best model, as defined by a high R^2 of 0.81 and lowest overall HQ (0.24), AIC (0.20) and BIC (0.29) values, was the model which included the one-, six- and twelve-month lagged yield spread along with the current and one-month lagged output gap variable. The six-month and twelve-month lagged output gap variables were found to be statistically insignificant, as was the contemporary yield spread. The results suggest that the yield spread takes longer than the growth rate in the output gap to be reflected in the probability of recession. The suggestion about the yield spread lag is consistent with previous research findings.

²⁰ Consensus Forecasts is a publication of the global macroeconomic survey firm Consensus Economics.

Out-of-sample testing was also performed using the above-selected model to forecast the probability of recessions with the forecast from one to nine months ($h=1 \dots 9$). The forecasts and probabilities were calculated using data available at April 2009. For the first month tested, April 2009, the probability of being in recession was 74.35 percent. The two-month lead, May 2009, calculated a probability of 44.11 percent. For June 2009, the month the NBER declared the most recent recession over, the probability declined sharply to 20.59 percent, then 6.95 percent for July, 1.90 percent for August, then 0.62 percent for September.

Given the results, the authors suggested that the model may be useful for not only determining start of recessions but also the end of recessions prior to the NBER's announcement. Additionally, the results demonstrate that the yield curve remains a useful forecasting tool for recessions--a tool that policy makers, investors and economists should consider continuing to use.

Summary and Considerations of Future Studies into the Yield Curve's Predictive Power

The compression or inversion of the spread between long-term and short-term bond yields, though not necessarily good at predicting point estimates for economic growth, has been a good predictor of recession starts over time. Currently, U.S. economic growth remains moderate. With increasing gasoline prices likely to curtail consumption, economic slowdowns in both Europe and China likely to curtail exports, and further expected cuts in national and local government expenditures, another recession in the near term is not out of the question.

The Federal Reserve remains steadfast in its near-zero interest-rate policy. Furthermore, under Operation Twist that began in September 2011, the Federal Reserve continues selling short-term Treasuries and buying long-term Treasuries. Long-term rates may thus be artificially low with the yield curve remaining distorted by the Federal Reserve Board's actions. Despite the yield spread's past forecasting success, because of the currently Fed-manipulated yield curve, the yield spread may not prove useful for policymaking and investing decisions in the near future. This should be of significant concern, given previous research results showing the yield curve to be useful in forecasting recessions--indeed frequently more useful than professional forecasts, some of which likely incorporate yield curve spreads in rendering their forecasts.

Following the start of the next recession, an analysis of the yield spread's forecasting ability should commence once again, using Estrella's probit model methodology to determine if the spread remains a predictive force even when manipulated downward by aggressive monetary policy actions.

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