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## Does the Yield Curve Predict Output?

Joseph G. Haubrich

Does the yield curve have the ability to predict output and recessions? At some times and in certain places, of course! But many details are matters of dispute: When and where does the yield curve predict successfully, which aspects of the curve matter most, and which economic forces account for the predictive ability? Over the years, an increasingly sophisticated set of tools, both statistical and theoretical, have addressed these issues. For the US, an inverted yield curve, particularly when the spread between the yield on 10-year and 3-month Treasuries becomes negative, has been a robust indicator of recessions in the post-World War Two period. The spread also predicts future real GDP growth for the US, although the forecast ability varies by time period, in ways that appear to depend on monetary policy. The evidence is less clear in other countries, but the yield curve shows some predictive ability for the UK and Germany, among others.

Keywords: Yield curve, term structure, prediction, recessions.

JEL Codes: E43, G12, E32.

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# 1 INTRODUCTION

The ability of the yield curve to predict future output and recessions, part of the broader question of the time series and business cycle properties of interest rates, has been a concern of economists, financiers, and indeed the general public for many years. Since the advent of academic work in the late 1980s, the field has seen tremendous development in statistical techniques, economic models, and even in available data. Opinions about models, data, and even what constitutes prediction have developed over time. This article provides a survey of the area.

The predictive ability of the yield curve is easy to see at a simple level. **Figure 1** plots the difference between the quarterly averages of the 10-year yield on US government bonds (Treasury constant maturity) and 3-month yield (secondary market discount basis), NBER recessions, and year-over-year real GDP growth, for the US from 1953 to mid-2020. The yield spread drops before each recession, going negative (“inverting”) before most of them. With slightly different time aggregations or yield conventions some of the close calls, such as 1990, would show actual inversions. The most prominent false positive, the inversion in 1966, did presage slower growth, and indeed Friedman and Schwartz (1982) add 1966 as the start of a recession in their study of monetary trends. This chart also illustrates the two main strands in the literature: predicting output or recessions. Though many papers explore both approaches, they are distinct questions: one, a more linear, often regression-based approach that has a lot in common with a broad range of forecasting techniques, the other, estimating probabilities of discrete turning points. Turning points are hard to predict, and so the yield curve as a predictor of recessions has probably a greater salience in the field. Some recent work , using quantile regression which looks at the entire distribution of output shocks, has blurred this distinction (Manzan 2015, Giglio, Kelly, and Pruitt 2016).

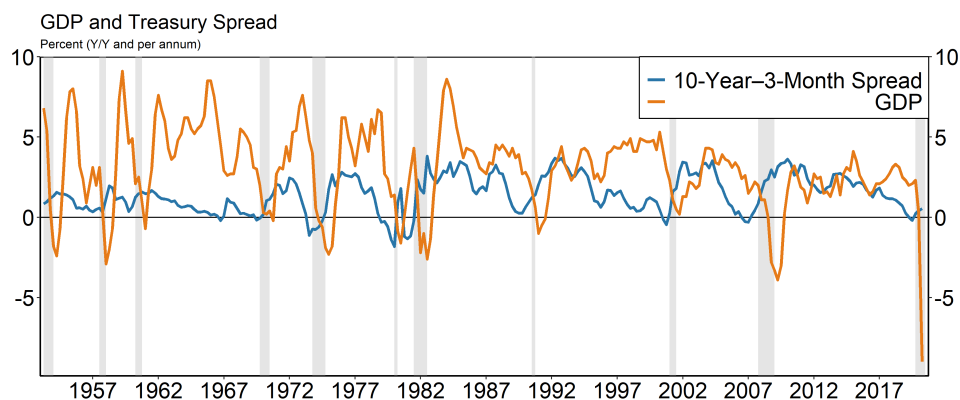


Figure 1: Spread between 10-year and 3-month Treasury yields, year-over-year real GDP growth, and NBER recessions. Source: Haver.

In a survey such as this, the choice of what to include unavoidably reflects my tastes and judgment of what is important. My apologies to authors I have been unable to include and to those authors whose papers I have treated in less detail than they deserve. Other surveys I have found useful in preparing this paper are Wheelock and Wohar (2009), and Estrella and Trubin (2006) and the extensive bibliography at the Federal Reserve Bank of New York's website: [https://www.newyorkfed.org/medialibrary/media/research/capital\\_markets/yield/biblio.pdf](https://www.newyorkfed.org/medialibrary/media/research/capital_markets/yield/biblio.pdf)

In the remainder of the paper I briefly describes the early, generally less formal work, two foundational papers, and later work in the field, which I organize around three questions: How does the yield curve predict output (what aspect of the yield curve is predictive)? Where and when does the yield predict output (i.e. across time and place)? Why can the yield curve predict output (what are the economics behind its predictive ability)?

## 2 TANGENTS

There are several closely related areas with their own extensive literature that I mention here only to indicate the bounds of this review. First is the question of how well the yield curve predicts inflation, itself part of an even larger literature on the relation between inflation and interest rates, long a concern of economists, probably first achieving modern form with the famous Fisher equation (Fisher, 1896, Dimond, 1999). Here Mishkin (1990) is representative of early work using regression techniques, with later work often employing more sophisticated yield curve models, as in Ang, Bekaert, and Wei (2008) or Haubrich, Pennacchi, and Ritchken (2012). The term spread, the difference between yields on bonds of different maturities, has its analogue in the credit spread, the difference between yields on safe and risky bonds, and an extensive literature looks at the ability of credit spreads to predict output. Work initially focused on credit spreads of various types, with Friedman and Kuttner (1998) looking at commercial paper, and Gertler and Lown (1999) looking at high-yield (junk) spreads. Gilchrist and Zakrajšek (2012) is a recent notable contribution that uses a more complicated construction.

There are a few places where the tests of how the yield curve predicts output are intimately related to particular theoretical models of the term structure, and certainly work on how and why the yield curve predicts output has a theoretical component, and will be addressed when relevant. In general, however, this review will not cover the vast literature on term structure models nor their empirical implementation and testing. Nice reviews can be found in Jarrow (2009) and Piazzesi (2010). Much of this work is an attempt to understand and estimate which factors move bond yields, both in an *ex post* and a predictive sense. An important strand of the literature looks at the impact of macroeconomic variables on interest rates, a literature ably

summarized in Gürkaynak and Wright (2012) and a recent representative sample being Campbell, Pflueger, and Viceira (2020).

Likewise, I will have little to say about the source of the interest rates used to construct the yield curve. Common sources include (in no particular order) Fama and Bliss (1987), McCulloch and Kwon (1993), Gürkaynak, Sack, and Wright (2007), and the Federal Reserve H.15 report, though some papers use other methods, and extracting a yield curve from bond prices remains an area of active research (Liu and Wu, 2020).

An area that deserves at least a mention is the extensive literature on macroeconomic forecasting. While the predictive content of the yield curve is not its main concern, papers are on the lookout for anything that helps forecast output, and at times the yield curve makes an appearance. Often, it is part of a suite of financial variables, as in Koop (2013) or Knotek and Zaman (2019), though the marginal contribution of the spread by itself is not split out. Stock and Watson (1989), in creating a new index of leading economic indicators, find the 10-year–6-month Treasury spread important enough to include in their new index, though it is not as important as a shorter risk spread. A few papers, such as Chauvet and Potter (2013) do try splitting out the yield curve, with mixed results.

### **3 EARLY WORK**

Work over the past 40 years has phrased the question as one of predicting output or recessions, but earlier work examined the issue from the standpoint of the business cycle properties of interest rates. Goode and Birnbaum (1959) noticed that short rates were high relative to long rates at the peak of the business cycle. Even earlier, Mitchell (1951) examined the business cycle properties of a variety of short and long rates. Kessel (1965) makes a more detailed study and concludes that (p. 63) “In general, the steepness or the degree to which yield curves were positively inclined decreased from trough-to-peak. Only about peaks could one observe yield curves with negative slopes.” This makes him among the earliest to note the importance of yield curve inversions, though again, like others of the time, he does not phrase his observation as a prediction.

Butler (1978) looks at the yield curve, notices an inversion, and suggests the market “seems to be anticipating a mild recession to begin in mid-1979.” Outside of academic work, the business press at times noticed the cyclical properties of the yield curve, though interpretations often differed. Heffernan (1957) saw an inverted curve as a sign of growth; later on Malabre (1987) saw it as indicating recession. In 1996 the Conference Board added the spread between the 10-year Treasury note yield and the federal funds rate to its index of leading economic indicators, later adjusting the spread to better pick up the predictive power of inversions (Zarnowitz and Lee,

2005).

## 4 FOUNDATIONAL PAPERS

The two papers most commonly cited as founding the modern work on the predictive ability of the yield curve appeared within a few years of each other. It pays to take a closer look at both because the way they frame the issues sets the stage for future work. If it is the case that Western European philosophy can be described as a set of footnotes to Plato then the work on how the yield curve predicts output can be described as a set of footnotes to Harvey and Estrella and Hardouvelis. Harvey starts from a strongly micro-founded theory of asset pricing, while Estrella and Hardouvelis look at the empirical facts and are somewhat skeptical of the theoretical explanations offered at the time.

### 4.1 Harvey

For those used to hearing how yield curve inversions predict recessions, the Harvey (1988) paper may come as a bit of a surprise, though its perspective is apparent in its title “The real term structure and consumption growth.” The paper tests an implication of the consumption-based capital asset pricing model. The emphasis is not on output but per capita consumption and the real interest rate.

Harvey starts from the consumer’s maximization problem, where consumption in each period depends on the endowment and the assets on hand, and the consumer must decide how much to consume and how much to save into each of the various assets. Specializing utility to constant absolute risk aversion,  $U(C) = \frac{C^{1-\alpha}-1}{1-\alpha}$  produces first-order conditions

$$E_t[\delta^j \left\{ \frac{C_t}{C_{t+J}} \right\}^\alpha (1 + R_{t,j})] = 1, \quad (1)$$

where  $R_{t,j}$  is the real interest rate between  $t$  and  $t + j$ , that is, the return on a real, riskless bond with maturity  $j$ , and  $\delta$  is the discount factor. Assuming that consumption and returns are jointly lognormal, the above equation can be rewritten as<sup>1</sup>

$$E_t[\delta^j \left\{ \frac{C_t}{C_{t+J}} \right\}^\alpha (1 + R_{t,j})] = E_t[\ln(\delta^j \left\{ \frac{C_t}{C_{t+J}} \right\}^\alpha (1 + R_{t,j}))] + \frac{1}{2} \text{Var}[\ln(\delta^j \left\{ \frac{C_t}{C_{t+J}} \right\}^\alpha (1 + R_{t,j}))] = 0. \quad (2)$$

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<sup>1</sup>Recall that if  $x$  is distributed lognormally, so that  $E(x) = e^{\mu + \frac{\sigma^2}{2}}$ , then  $\log E(x) = \mu + \frac{\sigma^2}{2}$ .

This can be rearranged to isolate the expected consumption growth terms

$$E_t[\ln(\{\frac{C_{t+j}}{C_t}\})] = \frac{j}{\alpha} \ln \delta + \frac{v}{2\alpha} + \frac{1}{\alpha} E_t[\ln(1 + R_{t,j})], \quad (3)$$

where  $v$  is the variance term, assumed constant. Notice this relates expected consumption growth to the expected real interest rate. Harvey does not directly test this implication but relates it to the yield curve as follows: subtracting (3) for  $j = 1$  from  $j = j$  and noting that  $\ln(1 + R_{j,t}) = \ln(\frac{1+R_{j,t}}{1+R_{1,t}}(1 + R_{1,t}))$ , the equation can be translated into an estimable regression

$$\Delta c_{t+j:t+1} = \beta_0^j + \beta_1 y_{s,t,j} + \beta_2 r_{1,t} + u_{j,t+j}, \quad (4)$$

where  $\Delta c_{t+j:t+1} = \ln \frac{C_{t+j}}{C_{t+1}}$ ,  $y_{s,t,j}$  is the yield spread, the difference between expected real yield  $j$  periods ahead and one period ahead, and  $r_{1,t}$  is the expected real short rate, that is, expected real rate for one period ahead. Note that Harvey is very specific about the relation between rates and consumption: a  $j$ -period rate, a real rate at that, is providing information about  $j$ -period consumption growth. So note the contrast with the earlier work of Kessel (and much later work, as we shall see): Not predicting business cycle turning points, but tying a specific real rate to consumption growth over the same time period.

This concern about real rates means that Harvey cannot use directly observed nominal rates;<sup>2</sup> he must estimate the expected real return. So in estimating his regressions, Harvey defines consumption as per capita nondurables and services, quarterly. For nominal bond yields, he uses 3-, 6-, and 9-month T-bills and the 1-year T-bond, monthly averages of daily prices. To create expected real rates, Harvey fits a time series model to the personal consumption deflator series to obtain expected inflation, and subtracts that from the nominal yield. Harvey also uses a GMM specification using *ex post* real rates. Harvey uses quarterly data from 1953:1–1987:1, with initial years used to estimate inflation, so the yield curve regressions are for the period 1959:1–1987:1, with results also broken up for two subperiods, 1959:1–1971:4 and 1972:1–1987:1. As mentioned earlier, one abiding concern of the literature has been a concern over which periods the yield curve shows predictive content, so it is important to note this question was present at the beginning.

Harvey presents the results for ine regressions (three time periods, three forecast horizons), and the results are mixed. The coefficient on the yield spread is never significant at the one-quarter horizon, and, though insignificant, the coefficient is negative for the early subperiod. The best results are for the 1972–1987 period for the two- and three-quarter horizons, where the coefficient is close to three times the standard error, and the  $R^2$  comes in at a respectable 0.28 and 0.31. It must be remembered that predicting consumption growth is no trivial matter:

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<sup>2</sup>Technically, of course, yields are calculated, as only prices are directly observed, but the transformation does not involve uncertainty.



A decade earlier Hall (1978) had shown that consumption was well-approximated by a random walk.

Harvey then compares the yield spread to other measures thought to predict consumption growth, such as lagged consumption growth and lagged stock returns. In regression results, the alternative measures do worse than the yield spread, with  $R^2$ s in the range of 2 percent to 6 percent. Harvey then compares the models using what are now known as pseudo-out-of-sample tests, where parameters are re-estimated at each point of the sample to predict future values. The yield curve model does better, as judged by either the mean absolute error or the root mean square error, though again the results are stronger for horizons of two or three quarters. Harvey's three methods of comparing forecast ability—statistical significance of a coefficient,  $R^2$ , and mean square error—provide the template for much of the future work in the area. (Later work will consider the significance of such differences.)

Finally, Harvey compares the yield curve model to predictions from seven large econometric models, including Chase, DRI, and WEFA. Results are somewhat mixed for the one-quarter forecasts, but at two and three quarters the yield curve model is the clear winner by mean absolute or mean square error.

## 4.2 Estrella and Hardouvelis

Estrella and Hardouvelis (1991) start from a more macroeconomic perspective. They note the opinion of business economists and analysts that the 1989 yield curve inversion presages a recession, and go on to ask how much extra information is in the term structure above other variables. To this end, they start with predicting the cumulative percentage change in real GNP (final, revised) regressing against the 10-year–3-month spread, using quarterly averages. The basic regression is

$$Y_{t,t+k} = \alpha_0 + \alpha_1 SPREAD + \sum_{i=1}^N \beta_i X_{i,t} + \epsilon_t \quad (5)$$

They estimate this equation for horizons of 1 through 20 quarters ahead, and for both cumulative changes ( $t$  to  $t+k$ ) and annual and quarterly marginal changes ( $t+j-k$  to  $t+j$ , for  $j=1,4$ ). The coefficient on the spread is significant at the 5 percent level out to 16 quarters, with  $R^2$  ranging from 0.13 to 0.38, and the spread variable is significant up to 7 quarters in the marginal growth regression, with naturally lower  $R^2$ s. The numbers are economically significant as well: Estrella and Hardouvelis calculate that a yield spread of negative 1.29 percent would indicate a negative growth rate 2 and 3 quarters in the future.

Having established that there is information in the yield curve, they look at several variations, first examining the ability to predict components of GNP, namely consumption, consumer

nondurables, investment, and government spending. The yield curve has predictive power for the private components, but not for government spending. Estrella and Hardouvelis point out that aside from its inherent interest, looking at components can be a way to differentiate between theories of why the yield curve predicts. They then look at how well the yield curve predicts recessions as defined by the NBER, by fitting a simple probit model, regressing a recession indicator against the slope of the yield curve 4 quarters earlier.

Estrella and Hardouvelis then add a short rate to the regression. Adding the real federal funds rate, the nominal federal funds rate, or the 3-month T-bill rate does not eliminate the predictive power of the yield curve. This suggests that the yield curve is capturing something beyond the current stance of monetary policy and also hints at the broader question: is the slope, or just the level of the term structure that has information about macroeconomic variables. They also add lagged output and the index of leading economic indicators: Even with these additional variables, the yield spread retains its predictive ability for both output and recessions.

Finally, Estrella and Hardouvelis compare the spread's predictive ability with that of the American Statistical Association/NBER survey of real GNP two and three quarters ahead. Both the in-sample regressions and the out-of-sample tests show that the yield curve predicts better than the surveys, though using both gives the best result.

Something was definitely in the air at the time, as several other papers emerged at roughly the same time as Harvey and Estrella and Hardouvelis. On the finance side, Fama (1986) and Stambaugh (1988) briefly noted some relations between forward rates and the real economy. Chen (1991), in a paper that looked for determinants of future stock market returns, looked at a suite of financial variables that by predicting future output, might also predict future returns. The spread between 10-year Treasury rates and T-bill rates shows predictive ability at up to 5 quarters ahead. Although well known in the general finance literature, it is perhaps less well known in the yield curve space because the title doesn't mention the yield curve. On the more explicitly macro side, Harvey (1989) looked at the ability of the 10-year-3-month spread to predict real GNP growth at a five-quarter horizon. Though Harvey finds that the yield curve has predictive power, both in out-of-sample regressions and relative to commercial econometric forecasts, he concludes that the model does not predict a recession for 1990, despite the inversion in 1989. Laurent (1988), looking for indicators of the stance of monetary policy, regresses the change in real GNP against the spread between 20-year Treasury yields and the federal funds rate and finds a significant relation at one lag. Stock and Watson (1989), creating a new index of leading economic indicators, find the 10-year-6-month Treasury spread important enough to include in their new index. The new index, however, failed to predict the low output growth associated with the recession of 1990, and in a follow-up paper, Stock and Watson (1993) attribute the failure

to their inclusion of financial variables, including the yield spread. Estrella and Mishkin (1998) later examined the issue and judged that it was the other indicators whose forecast ability broke down.

## 5 HOW?

Researchers have found that empirically, three factors account for most of the movement of the yield curve over time (Litterman and Scheinkman, 1991; Knez, Litterman, and Scheinkman 1994), often thought of as level, slope, and curvature, but of course for some purposes it may be more convenient to use other factors (perhaps latent). The early work by Harvey and Estrella considered spreads and short rates and so account for slope and level, finding the slope as the important factor, but later people began to revisit the issue.

The work looking at level, slope, and curvature generally employs a different methodology from the work that concentrates on spreads. The major technique in the earlier literature employed predictive regressions, often psuedo-out of sample. The level, slope, and curvature literature more often estimates a dynamic factor model of the macroeconomy and the term structure, with an emphasis on fitting the model, not on making predictions. Still, by considering explicitly dynamic models, these papers can explore the dynamic connections between variables in a way the simple regressions could not, even if they were out of sample. Dewachter and Lyrio (2006) fit such a model and uncover a macroeconomic interpretation of the latent factors behind the term structure. The level factor corresponds to a long-run inflation expectations factor, the slope factor is a mix of the output gap and shorter-term inflation expectations, and the curvature factor reflects the stance of monetary policy. Moench (2012) fits a more sophisticated but similar model and looks at the impact of surprise changes in each factor. The level factor reflects inflation, the slope factor influences output, though not very strongly, and the curvature factor presages a decrease in the slope and the level, leading to a flattening yield curve, which manifests before recessions. Diebold, Rudebusch, and Aruoba (2006) also estimate a factor model allowing bidirectional causality between the yield curve and the macroeconomy but find that a short rate, such as the federal funds rate, is essentially a sufficient statistic for the yield curve's impact on output.

Of course, the profession has also taken a closer look at the level factor. This has received some notice recently, as the very low level of interest rates has led some to question if the yield curve can still predict output or recessions when rates are at or near the zero lower bound. In one sense, however, the concern is not new, as many of the earliest papers explicitly account for the impact of short-term interest rates: Estrella and Hardouvelis find the yield curve still

has power even when adding the federal funds rate or the 3-month Treasury rate. Plosser and Rouwenhorst (1994) find that the slope of the term structure has information beyond short-term rates. Later work continued the trend. Ang, Piazzesi, and Wei (2006) find that the predictive content of the spread resides in the short rate, but Bordo and Haubrich (2008b) add in a short rate separately and find the yield curve still matters. Even earlier, in what is probably the most cited paper in this review, but one that does not get a lot of mention in the term structure literature, Bernanke and Blinder (1992), almost as an aside in their discussion of the transmission channel of monetary policy, find that the 10-year–1-year spread has little predictive ability above and beyond the federal funds rate.

In a paper both influential and representative of this branch of the literature, Ang, Piazzesi, and Wei (2006) use an arbitrage-free affine term structure model to impose cross-equation restrictions on the yield curve and GDP growth. Yields and real GDP are driven by a Gaussian state variable process

$$X_t = \mu + \Phi X_{t-1} + \Sigma \epsilon_t, \quad (6)$$

where  $\epsilon_t$  is IID  $N(0, I)$ ,  $\mu_t$  is a  $(K+1) \times 1$  vector, and  $\Phi$  is a  $(K+1) \times (K+1)$  matrix. The market prices of risk for the shocks are a linear function of the state variables

$$\lambda_t = \lambda_0 + \lambda_1 X_{t-1}. \quad (7)$$

The affine term structure models exploit the no-arbitrage condition and the linear Gaussian nature of the state variables and the affine nature of the prices of risk to express prices and thus yields:

$$y_t^n = -\log \frac{P_t^n}{n} = a_n + b_n^\top X_t \quad (8)$$

where  $a_n$  and  $b_n$  are constant matrices that are functions of the parameters.

Often these state-space factor models are estimated using maximum likelihood to extract some latent (unobserved) factors, but that is a computationally intensive procedure, and Ang, Piazzesi, and Wei are interested in out-of-sample forecasts as well, so they restrict their factors to observables: the short rate, the five-year–one-quarter Treasury spread, and GDP growth. Using a factor model summarizes the correlations between all the yield curve movements and GDP, and in addition keeps the yield curve changes internally consistent because it is an arbitrage-free model. These lead to more efficient estimation than a regression, and Ang, Piazzesi, and Wei can then exploit the factor structure dynamics to predict output. This is a major reason why they get different results on the relative importance of the short rate and the spread.

Some have gone beyond the three factors of level, slope, and curvature. Zhao (2020) empirically shows the importance of ambiguity for real and nominal bond yields, measured as the

dispersion in Blue Chip Financial Forecasts inflation expectations. Similarly, Giacomletti, Laursen and Singleton (2020) stress the implication of disagreement over expected yields. Cochrane and Piazzesi (2005) find an additional factor, a tent-shaped combination of forward rates, that is particularly important for explaining excess bond returns (though some, such as Bauer and Hamilton (2018), have questioned the robustness of their results). In fact the NBER working paper version has results showing that their factor can predict GDP 2-3 years in advance.

Ang, Piazzesi, and Wei also address another related question, namely whether expected rates or term premiums matter more. The expectations hypothesis posits that longer-term interest rates are the average of expected future short rates. Differences between those average expectations and observed interest rates are called term premiums and often ascribed to risk premiums or liquidity differences. If the yield spread does predict output, is the prediction coming from expected rates, the term premium, or some combination of the two? Ang, Piazzesi, and Wei find that the expectations have the predictive power, and that the raw spread, which includes the term premium, does worse because the term premium effectively adds noise.

Theirs is not the only word on the subject, however. Earlier, Hamilton and Kim (2002) apportion changes in the 10-year–3-month spread (from H.15 data) into expected future changes in the short rate and the term premium. Regression results show that both matter, but that expectations matter more, and the important factor is that low spreads imply falling short rates. They do not look at out-of-sample predictive differences. Favero, Kaminska and Söderström (2005) calculate the term premium in a different manner, using a real-time VAR for expectations, and find that the term premium does improve upon the predictive ability of expectations, and so both components contribute to the yield curve’s ability. Rudebusch, Sack and Swanson (2007), after an extensive theoretical discussion, look at five different measures of the term premium, settling on that of Kim and Wright (2005) for their empirical work. They do not find the level of the term premium significant for predicting growth, but changes matter: a decline in the term premium indicates faster GDP growth. Again, they do not conduct out of sample tests. Rosenberg and Maurer (2008), by contrast, find that expected rates matter, but the term premium does not, which confirms the initial results found by Rudebusch, Sack and Swanson. Bauer and Mertens (2018a), looking to predict recessions, find that separating the components does not improve the predictive ability of the spread. Lange (2018) looks at Canada and finds that the term premium is important for predicting GDP but that expectations are better for predicting recessions. Johansson and Meldrum (2018) note that adjusting for the term premium results in a lower probability of recession as of March 2018, but Bauer and Mertens (2018b) argue that such adjustments do not improve the predictive power of the spread.

Benzoni, Chyruk, and Kelley (2018) further break down the yield spread, dividing expected

rates into real and inflation components and dividing the term premium into real and inflation risk premia. (Rosenberg and Maurer (2008) mention this breakdown but do not use it.) Thus a nominal rate can be written

$$R = Er + E\pi + IRP + RRRP, \quad (9)$$

where IRP is the inflation risk premium and RRRP is the real rate risk premium. They also examine the components at different horizons: the spread for expectations is the 6 quarters 3-month spread, but for the two risk factors it is the 10-year–2-year spread. The net result is that a fall in the interest rate risk premium increases the probability of recession, while a fall in the real rate risk premium decreases the probability of recession. Thus a drop in the term premium can have different effects depending on which component is causing the increase, and this perhaps also accounts for some of the weak causality for the full term premium.

Lange (2018) criticizes much of the term premium work for its reliance on affine term structure models and prefers the approach of Crump, Eusepi, and Moench (2018), which uses surveys on the path of short rates to split out expectations and term premia. Lange concludes that the term premium has at best marginal information for predicting output, at least for Canadian data. Plakandaras, Gogas, Papadimitriou, and Gupta (2019) use support vector regression (SVM) techniques from machine learning to split out term premiums but find that neither the spread nor its decompositions have predictive power.

A somewhat smaller strand of the literature picks up from Harvey (1988) and considers the properties of real interest rate spreads. Argyropoulos and Tzavalis (2015) take advantage of the introduction of Treasury inflation protected securities (TIPS) in the US in 1997 to get a direct measure of the real term structure, and show that a two-factor affine term structure model can explain the correlation between real spreads and growth.

Roma and Torous (1997) go in an essentially orthogonal direction and argue that the proper relation is between interest rates and stochastically detrended output and consumption. They provide extensive theoretical justification, but also show that the 5-year–1-year spread has more information about the residual cyclical component from a stochastic trend than for the growth rate of GDP, at least for horizons of 6 to 10 quarters.

## 6 WHERE?

The initial work on the the yield curve and output looked at the United States, but scholars quickly became interested in how well the yield curve predicted output in other countries. Harvey (1991a) looks at the yield curve’s ability to predict changes in real GDP for the G7 countries,

and also for two world aggregates, over the period 1969-1989. Judging by both a significant statistic on the spread variable in the regression, and the  $R^2$ , the yield curve can predict future output for five of the seven countries, failing for Japan and the UK. This is robust to splitting the sample to account for when countries were on a fixed or floating exchange rate regime. Individual countries' output was highly correlated with the world measures, which were also predicted by a world yield spread, weighting each country by its share of world GNP.

Plosser and Rouwenhorst (1994) look not just at the predictive content of the yield curve but also at whether it contains information beyond predictions of monetary policy. They find that the yield curve has predictive power for consumption and industrial production in the US and Germany, but not for the UK, France, or Canada. Harkening back to Harvey (1988), Plosser and Rouwenhorst match the maturities of the term spread to the prediction horizon, arguing that such a prediction comes out of real business cycle theories. To account for monetary policy, they include not only a short interest rate, but also past and future growth of the money supply (M1), and the yield curve still has additional predictive power. Like Harvey (1991a) they look at a world interest spread, but they derive it as the first principal component of rates in the US, UK, Germany, and Switzerland. Estrella and Mishkin (1997) look at France, Germany, Italy, and the UK. With an emphasis on monetary policy, they first document that an increase in the central bank policy rate flattens the yield curve, with short-term rates rising more than long-term rates. The yield is a good predictor of recessions and for output, though the results for Italy are weaker.

The Federal Reserve Bank of Kansas City got into the spirit in a big way, with back-to-back issues of its *Economic Review* addressing cross-country comparisons in 1997. Bonser-Neal and Morely (1997) look at 11 industrialized countries using both in- and out-of-sample tests over the years 1971-1996. In sample, the yield curve predicts well one year ahead for all nations except Japan, judged both by  $R^2$  as a fraction of output variation accounted for by the spread term, or the significance of the coefficient. Germany and Sweden stand out as countries where the yield spread does particularly well in predicting changes in unemployment. In the out-of-sample test, Bonser-Neal and Morely compare the yield spread with regressions using lagged GDP growth and both the spread and GDP growth. In 21 of 33 cases (11 countries times 3 horizons) the spread by itself has the lowest RMSE. Kozicki (1997) looks at in-sample results for only 10 countries (skipping the Netherlands), but in addition to the spread, includes an estimated (short-term) real interest rate and the interaction between the spread and the real rate. The coefficient on the spread is positive and significant everywhere but Japan; with robust  $R^2$ s, the real rate matters about half the time, and the interaction shows up significant only for Italy and the UK. So the debate about level versus slope has its cross-country participants. Also published in 1997 was the work of Davis and Fagan (1997) who looked at out-of-sample results for nine countries in the EU, but the results were somewhat unstable across time.

Multicountry studies continued with Bernard and Gerlach (1998), who use probit regressions to predict recessions in eight advanced countries (including Belgium). At four to eight quarters, the yield spread has considerable predictive ability (except for Japan), even when an index of leading indicators is included. Foreign spreads are not significant, except for Japan, where Germany's matters, and the UK, where the US's matters. Moneta (2005), partly in response to Berk and Bergijk (2001), looks at the ability of the yield curve to predict recessions in the euro area, using an aggregation of GDP for 12 euro countries (excluding the UK) and using an aggregated yield curve. Moneta compares 10 different yield spreads, from 1-year minus 3-month to 10-year minus 5-year rates. But the standard 10-year–3-month spread remains the best, and beats lagged output growth in out-of-sample probits at one, two, three, and four quarters, with differences in RMSEs significant by the Diebold-Mariano (1995) test.

More recently, Chinn and Kucko (2015) suggest that the creation of the euro in 1999 and the advent of the zero lower bound in Japan and the US argue for a fresh look at the issues. They look at the ability of the 10-year–3-month spread to predict industrial production (monthly) one to two years ahead in nine countries over the span 1970-2013. Over the entire period, the spread is significant (even for Japan), though the  $R^2$  measure is not as high as in previous work reviewed. Results are not as strong at the two-year horizon. The yield curve predicts recessions as well, though in that Sweden is an outlier. Chinn and Kucko next use pseudo-out-of-sample regressions, comparing the yield curve against regressions with an AR(1) and 3-month rate, using the Diebold-Mariano (1995) test to assess statistically significant differences in the RMSE. Although equations using the yield curve have a uniformly lower RMSE, they are significantly better only in the case of Canada (5 percent level), and marginally so for Germany and the US (at the 10 percent level). Chinn and Kucko also look at the problem of data revisions: GDP gets revised over time (hopefully becoming more accurate as more data arrive) and so the 1970:Q1 value observed in 1975 differs from the value observed in 1970:Q2. Chinn and Kucko use a vintage real-time data set to account for this, but the differences do not seem large.

Other work looks more specifically at individual countries. Harvey (1991b) looks at Germany over the time period 1969-1991, and using both in-sample and rolling pseudo-out-of-sample regressions found the yield curve could beat both an econometric model and consensus forecasts. Davis and Henry (1994) look at the United Kingdom and Germany, using a 10-equation vector autoregression (VAR) that included the exchange rate, current account balance, money supply, and government deficit. They find that financial spreads, including the term spread, can help predict output even after accounting for a large number of other variables. This result survives being re-estimated in a vector error correction model (VECM) to account for cointegration among the variables, several of which are nonstationary. Harvey (1997) looks at Canada and in particular, shows that the Canadian term structure has information above and beyond that of the US term



structure for Canadian output growth.

Testing the predictive content of the yield curve for individual countries and areas is a rich enough area to deserve its own survey, and indeed it would take a linguist to do it justice. Some representative papers would include Kuosmanen and Vataja (2014) on Finland, Botha and Keeton (2014) on South Africa, Kaya (2013) on Turkey, and Tabak and Feitosa (2009) on Brazil. In addition to extending results to particular countries, these papers take a variety of statistical approaches and also provide evidence on how the predictive ability of the yield curve varies with the monetary policy, the exchange rate regime, and the openness of the economy.

## 7 WHEN?

One of the most studied questions has been how the yield curve's predictive ability has changed over time. This is naturally tied in with questions of what lies behind the predictive ability, and how changes in financial markets, monetary policy, and the economic environment may affect that ability. As seen above, the original Harvey 1988 paper looked at different time periods, and broke the 1959-1987 data into 1959-1971 and 1972-1987, finding that the yield curve does better in the latter period. Further work has followed this, as increasingly sophisticated econometric tools have been employed to assess the differences across time. Hardouvelis (1988) is representative of a broad class of papers looking at "The Predictive Power of the Term Structure during Recent Monetary Regimes," but looks only at the ability to predict future interest rates; it is perhaps surprising, then, that Estrella and Hardouvelis (1991) did not pursue the issue.

Haubrich and Dombrosky (1996) were among the first to note a shift. They compare the yield curve regressions to naive forecasts, lagged GDP, and leading indicators, finding that the 10-year-3-month spread is the best predictor of four-quarter-ahead real GDP growth as judged by RMSEs for the entire 1965:1-1995:3 period, but it is the worst for the 1985:3-1995:3 period. Dueker (1997) looks at the ability to predict recessions and uses a Markov-switching model, so that the coefficients in the regression can differ depending on whether or not the economy is in a recession. He argues that the spread does better at predicting major recessions and attributes the results of Haubrich and Dombrosky to the mildness of the 1990 recession rather than to any change in predictive ability. Making this a trifecta for Federal Reserve district banks, Dotsey (1998) argued for a re-evaluation because of the yield curve's failure to predict the 1990-1991 recession, and adds several lags of short rates and a dummy for Federal Reserve tightening to his predictive regressions. Looking at out-of-sample predictions from a rolling regression, none of the additional specifications does significantly better than the yield spread for the whole 1970-1997 sample. For the more recent 1985-1997 period, however, the yield curve does worse, with a RMSE

that is significantly lower by the Diebold-Mariano test. Estrella and Mishkin (1998) argue that the yield spread was in fact one of the better predictors of the 1990 recession and make a careful, out-of-sample comparison with a variety of different models and indicators.

Rounding out the work of the 90s, Stock and Watson (1999) briefly mention the yield spread in their magisterial overview of business cycles. Using a band-pass filter that detrends the data and isolates cycles of six to eight quarters, they note that while visually the yield spread lags output, it also Granger causes output with one of the higher  $R^2$ s among the series they examine. It is also an unstable relationship, with the QLR test (Quandt, 1960) finding a break in 1972.

Estrella, Rodrigues, and Schich (2003) follow Stock and Watson in using breakpoint tests, in their case the supLM test of Andrews (1993) and the supPR test of Ghysels, Guay, and Hall (1997). There is weak evidence (at the 10 percent level) from the LM test for a break in September 1983 for the equation predicting US industrial production but no evidence of a break for predicting recessions. Jardelet (2004), looking at the prediction of real GDP, uses a Bai-Perron (1998) test for multiple breaks and rejects no break against the alternative of one break in the first quarter of 1984, but cannot reject one break against two breaks. Rather than just test for breakpoints, Chauvet and Potter (2005) use Bayesian methods to allow time-varying parameters and autocorrelated errors in probit predictions of recessionary periods, finding they both contribute to the fit of the model. In what has to be one of the few triumphs of the slow paper review process, the lag between the original and the published version of their paper enables them to conduct a small but genuine out-of-sample test, with their models correctly predicting the recession that began in March of 2001, although the more complicated of their models had a less precise signal.

Galvão (2006) points out that structural break tests may be picking up a nonlinearity in the relationship and argues that a model combining both, namely, the structural break threshold VAR model, can explain, and correct, the deterioration in the yield curve's predictive ability. Chauvet and Potter, in their 2013 chapter in the *Handbook of Economic Forecasting*, come to the related conclusion that the forecast ability is contingent. They compare the predictive ability of a variety of models, including a VAR with the 10-year–5-year spread. The model is among the best at predicting output in normal times, but its predictions deteriorate in recessions, and, for the entire period, is among the worst of the broad range of forecasts they explore.

Barbara Rossi has looked at changes in the forecasting ability of the yield curve as part of a broader exploration of forecast breakdown. Giacomini and Rossi (2006) argue that a structural break does not necessarily imply a decrease in forecast ability. They apply a forecast breakdown test based on Giacomini and Rossi (2009). The test regresses the “surprise loss,” the difference between the observed loss and the in-sample loss, against estimated parameters of the Federal

Reserve's reaction function. They judge forecast breakdowns to occur during the Burns-Miller era (pre-March 1979) and in the Volcker era (April 1979-July 1987), but that the yield curve became a more reliable predictor of output in the Greenspan era (July 1987-June 2001, in their sample). Rossi and Sekhposyan (2010) look at a broader range of possible predictors. Of interest to us, the yield spread emerges as significantly better than the autoregressive benchmark, as judged by the Giacomini and White (2006) test. By their reversal test, the yield curve shows predictive ability from the mid-1970s to 1980, after which it appears to fade.

Shi, Phillips, and Hurn (2018) run a four-variable VAR and develop a "sup Wald" statistic that can demarcate times when the yield spread Granger causes output (they look at industrial production). That gives it a somewhat different flavor than the work using other tests of predictive ability. Like Rossi and Sekhposyan, they can pick out periods of predictive ability, but unlike Rossi and Sekhposyan, they find only a few short periods of causality, in 1998 and 2009.

The work mentioned so far has looked at "when" by looking for changes over the post-World War Two period, using increasingly sophisticated econometric methods. Another strand of the literature has looked at "when" by expanding the time horizon and looking at historical data. This of course brings up questions of comparability, as instruments such as 3-month T-bills did not always exist, and even Treasury bonds were not obviously the least risky form of debt. Still, a longer history provides a larger set of business cycles and financial and monetary conditions: one simply can't blame the recession of 1890 on the FOMC raising the fed funds rate! Bordo and Haubrich (2008a) judge predictive ability by the ratio of the mean square error in a regression with the spread and past values of real GNP relative to a regression with just past values. The results confirm much of the previous analyses by finding that the yield curve regressions do well in the 1971-1984 period and deteriorate afterward, but they also find that yield curve regressions are superior in the 1875-1913 time period, and indeed have predictive ability on the entire 1875-1997 sample taken as a whole. Benati and Goodhart (2008) look at a similar sample and find little gain in predictive ability in adding the yield spread to a VAR with output, the short rate, and inflation. Their use of a VAR with time-varying coefficients and stochastic volatility represents a gain in econometric sophistication, but comes at the cost of added complexity and produces only in-sample results. As another attack on this historical data, Bordo and Haubrich (2020) use the techniques of Shi, Phillips, and Hurn (2018) to test if the yield curve has lower predictive ability in periods of low interest rates, but in general they don't find a difference.

## 8 WHY?

### 8.1 Theory

Why does the yield curve predict output? What economics lie behind the predictive ability? Harvey (1988) gave an answer early on, but his answer depended on using real rates and the maturity of the interest rates matching the prediction horizon. It did not account for what became a very robust empirical result that the difference between 10-year and 3-month nominal rates predicts real GDP growth over the next year. Estrella, Rodrigues, and Schich (2003) in an appendix provide a habit formation model that can explain why the slope of the yield curve predicts output, though they are not clear about the time horizons involved and correctly point out that, like Harvey (1988), the prediction is for the real term structure.

Rendu de Lint and Stolin (2003) follow Harvey (1988) in looking at predictive ability from an asset pricing perspective. They argue, however, that Harvey's assumption of joint lognormality between interest rates and consumption may rule out empirically plausible endowment patterns. In fact they show that if endowments follow the process  $\ln(y_{t+1}) = \rho \ln(y_t) + u_{t+1}$ , then the yield spread will be *negatively* correlated with output growth, because shocks have a larger impact on income and thus consumption in the first period. It might be of interest to see if a plausible endowment process in fact generates a positive correlation, and indeed a variety of papers such as Labadie (1994) look at such correlations without directly addressing the predictive content of the spread, but Rendu de Lint and Stolin go a different route, looking at a stochastic production economy. In an economy where agents can invest in productive capital, simulations with parameters chosen to match the US data show that the yield spread will be positively correlated with future consumption growth. Equally important, the model provides a bridge to other empirical work by showing that the yield spread can predict output as well.

Earlier, Hu (1993) proposed a continuous time model with one good that can be either consumed or invested. The productivity process pins down the short-term interest rate as a function of the mean and variance of productivity growth, and given a variance, a higher mean indicates a higher interest rate, which indicates a positive relation between the spread and output growth. Berardi and Torous (2005) likewise use a continuous time model with two underlying factors, and assume a constant inflation rate to connect real rates, nominal rates, and real consumption.

Smets and Tsatsaronis (1997) are interested in determining if the yield curve's predictive ability derives from fundamentals or policy-driven shocks. They set up a four-equation VAR with GDP, inflation, the 3-month rate, and the 10-year–3-month spread. Relative to much of the previous VAR work in the area, this is an identified VAR, with an error structure on

four shocks: aggregate demand, aggregate supply, monetary policy, and a shock to long-term interest rates that, following Goodfriend (1995), they term an “inflation scare.” They identify the VAR by restrictions on the shock effects. For example, demand shocks have no long-run impact on output, and monetary policy has no contemporaneous effect on output. Decomposing the variance between the yield spread and current and future output growth, they find that “leaning against the wind” policy accounts for much of the positive correlation between the term spread and output. However, they also note that supply shocks, which increase future output, also significantly steepen the yield curve in Germany, while the US curve barely responds. Furthermore, the inflation scare shocks, which have little impact on output, account for a lot of the movement of the yield curve in the US, but not in Germany, further accounting for the stronger correlation seen in Germany.

Feroli (2004) succinctly explains one very prominent theory behind the ability of the yield to predict: A rise in the short-term rate (usually tightening by the central bank) will flatten the yield curve as well as slow real growth. Hence, a flatter yield curve will precede a slowdown in output. Feroli provides an example whereby the predictive ability of the yield curve comes from the reaction of the central bank, which sets short-term interest rates. It is a consequence of the expectations hypothesis and the assumption that monetary policy follows a Taylor rule and reacts to an output gap and deviations of inflation from a target rate.

A key component of Feroli’s explanation is the Taylor rule (Taylor, 1993), which describes how the central bank sets this period’s short rate  $i_t^1$

$$i_t^1 = \rho i_{t-1}^1 + (1 - \rho)[i^* + \beta(E_t \pi_{t+1} - \pi^*) + \gamma E_t y_{t+1}], \quad (10)$$

where  $\rho$  is the interest rate smoothing parameter,  $i^*$  is the target nominal interest rate,  $\beta$  is the weight placed on deviations between next period’s expected inflation and the target inflation rate  $\pi^*$ , and  $\gamma$  is the weight placed on the output gap  $y_{t+1}$ , the expected difference between actual and potential output.

A simple two-period example will demonstrate the logic. Assume the pure expectations hypothesis, so that longer term rates are just the average of expected short rates (so note this is ruling out any role for the term premium by assumption).

$$i_t^2 = \frac{1}{2} E_t(i_t^1 + i_{t+1}^1). \quad (11)$$

The spread  $S_t^{2,1} = i_t^2 - i_t^1$  can be expressed as

$$S_t^{2,1} = \frac{1}{2}(E_t i_t^1 - i_t^1), \quad (12)$$

or, using the Taylor Rule (10) for  $i_{t+1}^1$

$$S_t^{2,1} = \frac{1}{2}[E_t\{\rho i_t^1 + (1 - \rho)[i^* - \beta(E_{t+1}\pi_{t+1} - \pi^*) + \gamma E_{t+1}y_t + 1]\} - i_t^1] \quad (13)$$

Applying the law of iterated expectations and collecting terms

$$S_t^{2,1} = \frac{1 - \rho}{2}[i^* - \beta(E_t\pi_{t+1} - \pi^*) + \gamma E_t y_t + 1 - i_t^1], \quad (14)$$

producing

$$E_t y_{t+1} = \frac{2}{\gamma(1 - \rho)} S_t^{2,1} - \frac{1}{\gamma}[i^* - \beta(E_t\pi_{t+1} - \pi^*) + -i_t^1]. \quad (15)$$

Equation 15 expresses future output in terms of the spread. The relation also depends on the short rate and on the parameters of monetary policy  $\rho$ ,  $\beta$ , and  $\gamma$ . A reactive monetary policy can lead to a yield curve predicting output, even if there is no causal connection. Furthermore, changes in the monetary policy regime, in the sense of changes in the Taylor rule parameters, can change the predictive ability of the yield curve. But note that this example does not quite account for the empirical results seen above. It is for the future output gap, not the growth in future output (though the two may be correlated), it does not account for any term premium, and it does not have any explicit mechanism whereby monetary policy may cause the output drop. Feroli addresses these concerns by simulating a three-equation New Keynesian model. He notes that under the assumptions of the model, the agents in the economy know the equations, so while the yield spread can be expressed as a function of future output, observing it does not provide more information, which in some sense is at odds with the idea of using the spread as a forecasting tool.

Estrella (2005) considers two versions of a five-equation model that is still simple enough to be solved analytically. The macro side of the model consists of an IS curve, which relates output and interest rates; a Phillips curve, which relates output and inflation; and a Taylor rule that relates the policy interest rate to output and inflation. To these he adds a Fisher equation relating real and nominal interest rates, and an expectations hypothesis relating short- and long-term interest rates. Expected future output depends on the yield spread, the short rate, the current inflation rate, the target inflation rate, and current output. The weighting depends sensitively on the Taylor rule parameters governing the reaction of monetary policy, that is, on the response to output and inflation and on the degree of interest rate smoothing. The slope of the Phillips curve also matters. Strangely, the parameters of the IS curve do not. Several lessons emerge. First, the yield curve predicts future output, but the short rate also matters. Furthermore, the importance of the yield curve depends on the response of monetary policy, so changes in the monetary policy regime are likely to have an impact on the yield curve's predictive ability. Two

broader observations should also be made. First, having a model illuminates the conditions when the yield curve is expected to predict well and when it isn't, and secondly, as the model is relating two endogenous variables, many simple stories appear, well, simplistic.

Rudebusch, Sack, and Swanson (2007) argue that the workhorse linearized New Keynesian model can express output in terms of short-term interest rates, and hence the term premium can play no role, though expectations of future rates matter. When looking at a more structural New Keynesian DSGE model, they note that the correlation depends on the particular shock: Monetary and technology shocks raise the term premium but decrease output, while a monetary shock increases both. Though they caution that the response of the term premium to these shocks is small in the calibrated model, it should be noted that differences in shocks offer a potential explanation for differences across countries and across time.

De Graeve, Emiris, and Wouters (2009) work with a DSGE model that includes a time-varying inflation target. Though their macro model is much smaller than Morell's (see below), they do not assume the expectations hypothesis, and their model provides an estimate of term premiums. They explicitly ask why the yield curve forecasts growth and find the answer in several shocks. A demand shock increases inflationary pressure, which induces the monetary authority to increase the short rate, leading to a flatter yield curve, while the shock also leads to an immediate increase in consumption and investment, which then return to normal, leading to the observed correlation between a flatter curve and slower growth. The wage markup shock also leads to such a correlation, as monetary policy reacts to counter the inflationary pressure by increasing the short rate, which lowers growth. De Graeve, Emiris, and Wouters note that the important variable here is the short rate and suggest that their work provides a structural explanation for the results in Ang, Piazzesi, and Wei.

Kurmann and Otrok (2013) attack the problem by estimating a VAR with the spread and macro variables but take a different approach from earlier work. They extract the exogenous shocks that explain the forecast error variance (FEV) of the yield curve slope, rather than looking at the impact of shocks to the VAR components. They identify a slope factor that accounts for 75 percent or more of the slope FEV. They then obtain an economic interpretation of this factor by putting it back into the VAR and interpreting the impulse response functions. The factor has slow-moving but permanent effects on total factor productivity (TFP), and they interpret this as capturing news about innovations to TFP, a result confirmed by its high correlation with an independent calculation of such a news factor. Furthermore, the factor shifts the federal funds rate, but the correlations with inflation indicate that it represents not exogenous shifts in monetary policy, but an endogenous response. Finally, the factor leads to an immediate and large jump in the yield spread but to a gradual increase in consumption and real GDP, thus

explaining the correlation between the yield spread and future growth.

Morell (2018) addressed this question by taking the DSGE model of Smets and Wouters (2007) and adding an expectations hypothesis theory of the term structure. He is thus working with an empirically much more sophisticated macroeconomic model than previous work, with 44 parameters (4 calibrated, the rest estimated) and 20 equilibrium conditions. After first documenting that the term spread's predictive ability deteriorated from the 1966:1–1979:2 period to the 1982:1–2006:4 period, he then looks at what structural changes occurred in the estimated model between those periods. While the monetary policy reaction function became less sensitive to output and the New Keynesian Phillips curve became flatter, those changes do not account for the bulk of the change. Rather, a change in the composition of underlying shocks to the economy had the larger impact. Morell decomposes the correlation between the spread and future output growth to each structural shock. In the 1966–1979 period, three shocks dominated the correlation: the monetary policy shock, the risk premium, and the investment shock. In the later period, the risk premium shock, usually interpreted as shocks to the demand for safe, short-term assets such as US Treasury bills, and the monetary policy shock, exogenous increases in the federal funds rate, became less important. The investment shock, which also captures the efficiency of credit intermediation, became more important. But in the model, investment shocks don't shift the yield curve in a way that precedes output, so their increased importance reduces the leading indicator property of the yield curve.

Kung (2015) takes a New Keynesian DSGE model to which he adds endogenous growth and recursive preferences. The Taylor rule is key to the predictive ability of the yield curve. A productivity shock increases expected consumption growth and decreases inflation. The monetary authority responds by lowering the short-term rate. As future short rates are expected to be higher, this steepens the yield curve. This relies on a rather specialized Taylor rule, one where the response to inflation is higher than the response to consumption and the drop in the short rate exceeds the drop in the long rate coming from lower expected inflation.

## 8.2 Empirical

In papers such as Feroli, Hu, and Rendu deLint and Stolin, the yield spread serves as a predictor because it provides information about the economy; it does not have a causal role. Papers based on New Keynesian models are perhaps more ambiguous in this regard, as the IS curve links interest rates and output. Adrian, Estrella, and Shin (2019) test an explicitly causal story where shifts in the yield curve cause the output response. Monetary tightening flattens the yield curve, which drives down the net interest margin of banks (which use short-term deposits to make long-term loans), leading to less lending and a contraction in the supply of credit. In making their



point they also provide evidence for the impact of monetary policy on the yield curve and for the balance-sheet channel of monetary policy.

Lenel, Piazzesi, and Schneider (2019) propose such a model of how interest rate policy shocks are transmitted to the rest of the economy via bank balance sheets. Banks create money by holding short-term securities, and this creates a convenience yield for the short-term assets. A key point of such intermediary-based asset pricing theories is the disconnect between the interest rate on short bonds and expected consumption growth, and in that sense they directly deny the explanation in Harvey's original 1988 work. Lenel, Piazzesi, and Schneider also postulates a new spread that matters for macroeconomic activity, the "shadow spread," between the actual short-term rate and the short-term yield implied by the rest of the yield curve.

Baumeister and Benati (2013) use periods of a zero lower bound to identify pure spread shocks, where large-scale asset purchases lower the long-term interest rate and compress the spread. They find that these compression shocks exert a powerful positive effect on output growth in both the US and the UK. This suggests that, at least at the zero lower bound, monetary policy that changes the yield spread has a causal effect on output growth but in the opposite direction usually assumed: A lower spread increases growth. In this their results are similar to the results of the extensive literature that uses calibrated DSGE models to assess the impact of quantitative easing and other unconventional policies, though the impact on the forecast abilities of the term spread is generally not explicitly considered. The paper by Sims and Wu (2020) contains a recent representative model and a good discussion of the literature.

In a more empirical vein, Engstrom and Sharpe (2019) also propose a new spread and argue that because it better captures upcoming movements in the short-term rate it provides better predictions than the traditional yield spread. Kamara (1997) had earlier argued that the spread between a 12-month T-bill rate implied by the futures market and the spot rate on a 3-month T-bill could predict growth in consumption, investment, and GDP. Engstrom and Sharpe look at the "near-term forward spread," the implied rate on a 3-month T-bill 6 quarters ahead less the rate on a current 3-month T-bill. They suggest that if that spread is negative, it likely reflects an easing of monetary policy because the authorities expect a recession. They provide evidence that it is a superior predictor to the long-term 10-year-2-year spread, further suggesting that the predictive ability of the long spread comes from the short end and that adding long rates adds noise, for example, from changes in inflation expectations. The results are impressive, but it remains to be seen if the predictive ability will hold up over time.

## 9 CONCLUSION: TOWARDS THE FUTURE

I think future research on the forecast ability of the yield curve should, and probably will, progress in four main areas. First, increasingly sophisticated statistical tools will be brought to bear on the issues of causality, stability, and the meaning of prediction. Papers cited here have already used wavelets, machine learning, and techniques to model the entire distribution of output. Second, as theories of the term structure advance, they will have more to say about how and why the yield curve predicts output. Third, in a similar fashion, as DSGE, New Keynesian, and other macro models advance and incorporate more sophisticated financial sectors, our insight into the macro–yield-curve connection should increase. And last, yield curve predictions of output have been common for decades, so true out-of-sample comparisons should be possible. The Federal Reserve banks of New York and Cleveland both put out forecasts. <https://www.clevelandfed.org/en/our-research/indicators-and-data/yield-curve-and-gdp-growth.aspx>, and [https://www.newyorkfed.org/research/capital\\_markets/ycfaq](https://www.newyorkfed.org/research/capital_markets/ycfaq).

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The author is not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

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