Appendix – Assessing US recession risks

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This appendix provides further technical detail to Anthonisz (2022).

Section A1: Studies into ability of yield curve to forecast recessions

Table A1 sets out the key findings from a collection of studies into the predictive ability of the yield curve for recessions in the United States.

TABLE A1: RECENT STUDIES INTO THE PREDICTIVE POWER OF THE YIELD CURVE FOR US RECESSIONS

Study	Finding
Bauer & Mertens (2018a)	The flattening of the yield curve slope is generally the result of large increases in short-term yields. The yield curve (1-year/10-year) has accurately predicted each recession back to 1955 with a lead time of six to 24 months with only one false positive. Lower neutral rates and term premia have not distorted the predictive power of the yield curve.
Wright (2006)	The 3-month/10-year yield curve has explanatory power in forecasting recessions, though results are improved when adding the level of the Federal Funds Rate. Controlling for term premia may also help.
Liu & Moench, 2014	The 3-month/10-year yield curve has the best predictive power for recessions 12 to 18 months ahead. Six-month lags of the spread and measures of financial sector leverage (for example, margin lending on the NYSE) add to the information in the yield curve for horizons less than a year.
Bauer & Mertens (2018b)	The 3-month/10-year yield curve has the best predictive power for recessions 12 months into the future, though it is only marginally better than the 1-year/10-year curve, 'Near-term Forward Spread' and 2-year/10-year curve. Removing the term premia component of bond yields to only leave the 'expectations' component results in worse predictive power but adding the term premia component does not add any explanatory power in addition to what is in the yield curve.
Rosenberg & Maurer (2008)	A yield curve slope which only reflects the expectations component of yields produces similar estimates of recession probabilities to a standard yield curve. A slope which reflects only the term premia component performs poorly but one with both components has a fit that is comparable to a standard yield curve (though with the term premia component insignificant and suggesting that the 'expectations' component is the key driver).
Backer, Deroose & Van Nieuwenhuyze (2019)	The flattening of the yield curve slope is generally the result of large increases in short-term yields. Despite a change in how long-term yields have moved when short-term yields have increased, the yield curve has retained its ability to forecast recessions. The 'expectations' component of yields seems to drive the overall recession forecasting power of the yield curve. The 'Near-term Forward Spread' doesn't out-perform models which only include the 'expectations' components of yields.
Johansson & Meldrum (2018)	In the last decade there have been times that yield curve (3-month/10-year) based recession probabilities overstate the likelihood of recession. Using models featuring the first three principal components of Treasury yields, yield spreads adjusted for term premia, or other variables such as the Excess Bond Premium suggests recession probabilities were lower over this period.
Miller (2019)	There is no one indicator that is best at forecasting recessions. If using yield spreads, the most accurate one will depend on the future time horizon that the recession probability is being assessed over. If one indicator were to be selected it should include the first three principal components of Treasury yields.
Benzoni, Chyruk & Kelley (2018)	This article breaks down yield curve slopes by looking at both the expectations and term premia component of yields. Explains why the change in these different components could signal a future recession. A recession probability model including information from this decomposition provides more accurate forecasts of recessions than the 2-year/10-year yield curve slope.
Haltom, Wissuchek & Wolman (2018)	Low term premia make the chances of a yield curve inversion more likely even if the probability of a recession has not increased.

Study	Finding
Engstrom & Sharpe (2018)	The 'Near-term Forward Spread' (that is, the spread between the six quarter ahead three-month rate and the three-month rate) out-performs traditional yield curve measures such as the 3-month/10-year and (especially) the 2-year/10-year spreads.
Engstrom & Sharpe (2022)	The flattening of the 2-year/10-year curve is inconsistent with the increase in the Near-term Forward Spread and, given the latter, there is no indication that recession risks have increased.
Ercolani & Natoli (2020)	Macroeconomic and financial uncertainty are useful indicators of recessions at short horizons (up to 7 months) while the 3-month/10-year yield curve is the best indicator for longer horizons.
Kelley (2019)	The Conference Board Leading Economic Index is the best indicator for recessions in the near-term (up to 9 months) while the 3-month/10-year yield curve is the best (or at least the best) indicator for longer horizons. There is value in aggregating different indicators into an index and using this to predict recessions.
Berganza & Fuertes (2018)	The low value for the component of the yield curve slope made up of term premia points to the possibility that the yield curve could invert for reasons other than reflecting changes in future rate expectations.
Ferrari & Le Mezo, 2021	An indicator constructed using text-based analysis out-performs the 3 month/10-year yield curve in the short-term (up to 8 months) and also contains useful information about recession probabilities that is not already included in the yield curve measure.
Favara et al (2016)	The component of credit spreads that reflects investor risk appetite as opposed to default risk – the 'Excess Bond Premium' – contains all the information in credit spreads that is useful in forecasting recessions.

Section A2: Yield curve (2-year/10-year) inversion episodes

This table shows highlights different historical instances when the 2-year/10-year yield curve has gone negative.

TABLE A2: KEY CHARACTERISTICS OF DIFFERENT YIELD CURVE INVERSION EPISODES

Date of inversion	Consecutive negative days after initial inversion	Days negative in first 12 months after inversion	How much later recession occurred
26-Feb-73	210	89%	9 months
12-Aug-75	1	2%	No recession
2-Aug-78	442	96%	17 months
22-Aug-80	8	93%	11 months
21-Dec-81	7	51%	Signal during recession
6-Jan-89	2	51%	18 months
20-Mar-90	2	1%	4 months
8-Feb-00	1	60%	13months
3-Feb-06	2	33%	22 months
14-Aug-19	1	2%	6 months [a]
1-Apr-22	1	3%	?

Note: Blue shading represents unusual outcomes: *August 1975* (false signal), *December 1981* (signal occurred while already in recession), *March 1990* (signal initially provided in January 1989) and *August 2019* (recession due to COVID-19 pandemic)

Source: Refinitv Datastream, QTC Economic Research

Section A3: Yield curve-based recession probability estimates

Various yield-curve based measures were examined to assess which were the most accurate indicators of a future recession. The data for these were available on a daily basis. Details about these measures are set out below.

TABLE A3: DIFFERENT YIELD CURVE BASED MEASURES AND THE UNDERLYING DATA SOURCE

Data source	Yield type
Gurkaynak, Sack & Wright (2006)	3-month/10-year 2-year/10-year First three principal components of US Treasury yields Second principal component of US Treasury yields Near-term Forward Spread[b]
Kim and Wright (2005)	First three principal components of 'expectations' element of US Treasury yields[a] Second principal component of 'expectations' element of US Treasury yields[a]
Adrian Crump and Moench (2013)	First three principal components of 'expectations' element of US Treasury yields[a] Second principal component of 'expectations' element of US Treasury yields[a]
US Federal Reserve	3-month/10-year

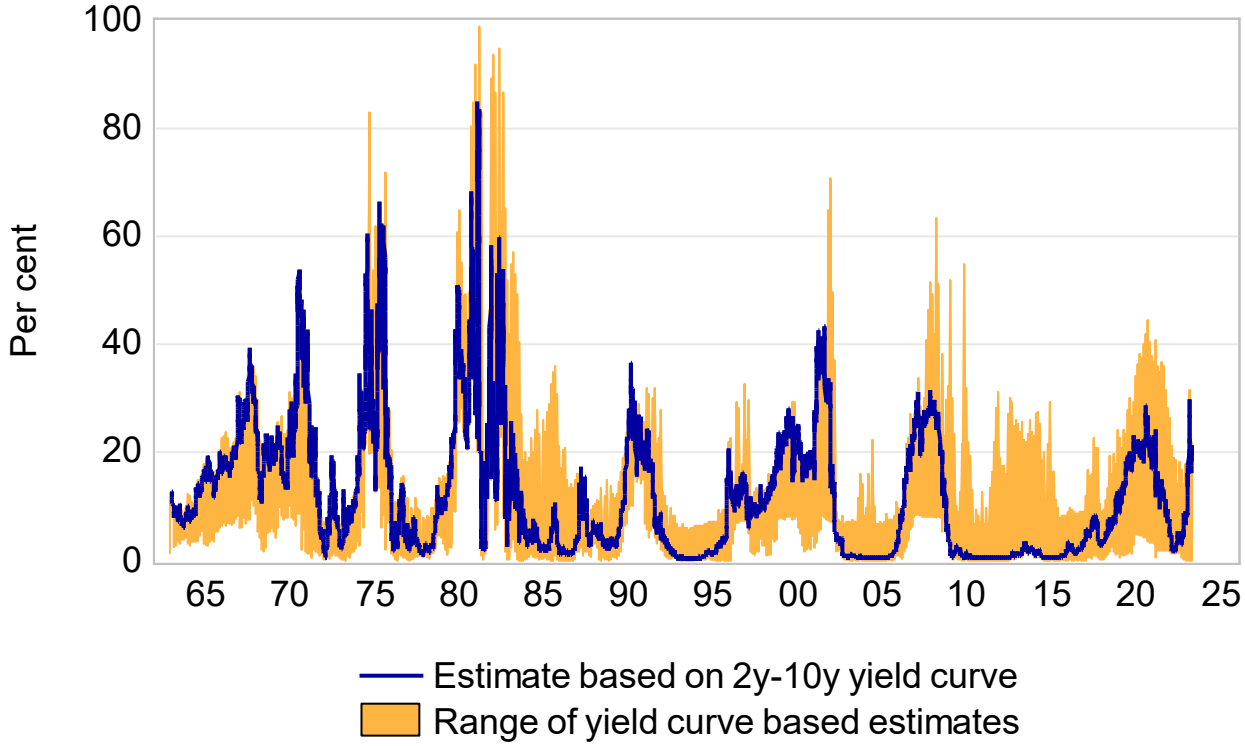
[a] – 'Expectations' element of yields in the Kim and Wright (2005) data taken to be the difference between forward rate and instantaneous forward term premium, while that in the Adrian Crump and Moench (2013) data is taken to be the risk-neutral yield

[b] – Author calculations based on data from Gurkaynak, Sack & Wright (2006) and method outlined in the appendix to Engstrom & Sharpe (2019)

Recessions were identified with a value of '1' as per the NBER's Business Cycle Dating Committee with an expansion given a value of '0'. These binary outcomes were the dependent variable in separate Probit regressions [see for example Estrella & Trubin (2006)] on 12 month lags of the independent variables listed in Table A2 above.

The range of recession probabilities estimated by these models can be seen in Graph A1 below.

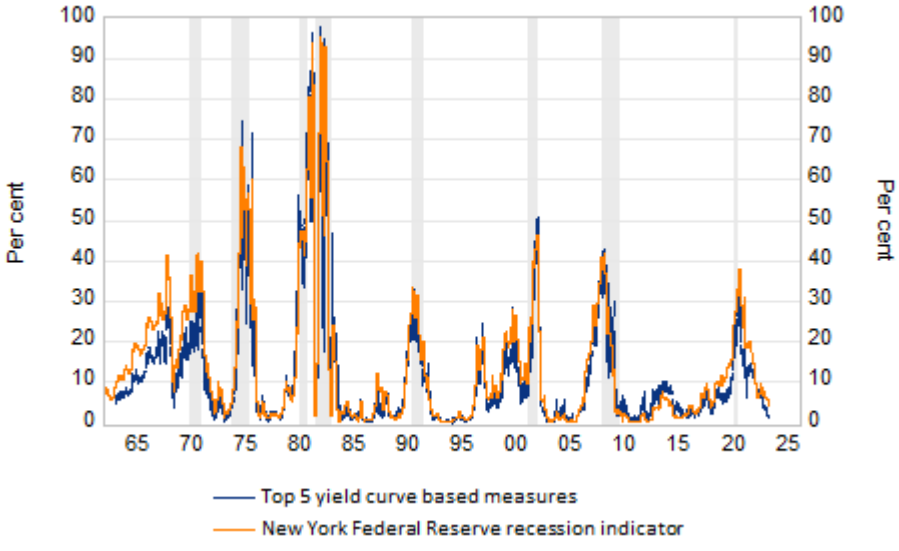
GRAPH A1: YIELD CURVE BASED RECESSION PROBABILITY MODELS



Source: Refinitv Datastream, Bloomberg, QTC Economic Research

The results were similar to the widely followed estimates from the New York Federal Reserve (Graph A2), though the advantage of my estimates are that they are available daily (rather than monthly from the New York Fed).

GRAPH A2: COMPARISON TO NEW YORK FEDERAL RESERVE ESTIMATES



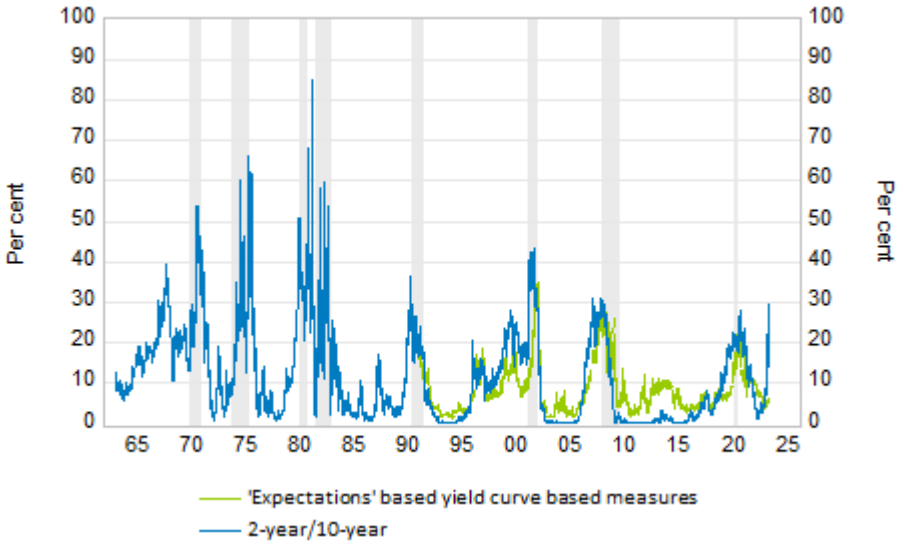
Source: New York Federal Reserve, Refinitiv Datastream, QTC Economic Research

Several robustness tests were employed though didn't lead to a material change in results.

First, I included the 'expectations' component of yields in the regressions. The rationale is that the interest rate expectations component of yields should be more informative for recession probabilities as opposed to the risk premia demanded by investors to hold bonds [Backer, Deroose & Van Nieuwenhuyze (2019)]. I found that:

1. Four of the five most accurate yield curve-based measures were those based on the expectations component of yields (see section A4 below)
2. The average of expectations-based measures[1] show similar peaks ahead of recessions to that of the 2-year/10-year spread (Graph A3)
3. These measures generally show a slightly higher probability of a recession during 'normal times'
4. The estimated probability based on the average of 'expectations' measures at present is quite low (5 per cent)

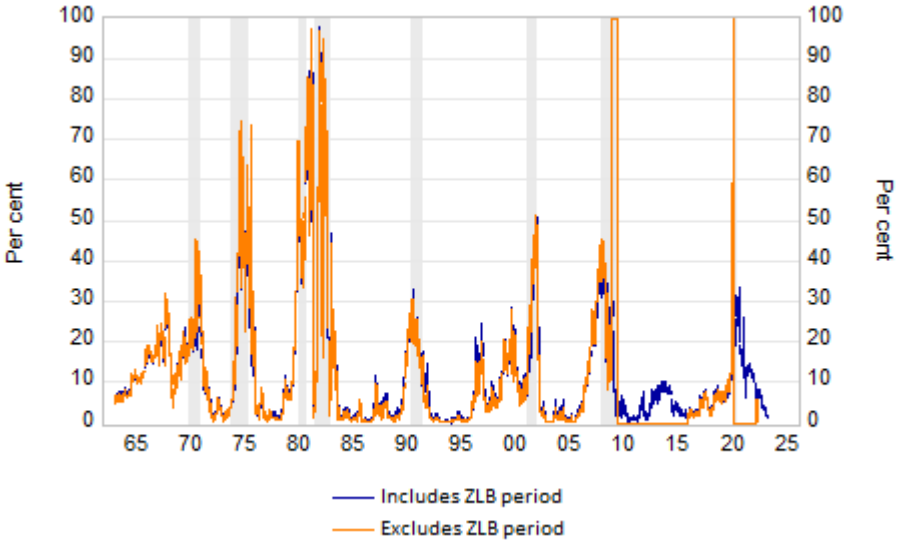
GRAPH A3: RECESSION PROBABILITIES AS PER 'EXPECTATIONS' BASED COMPONENTS OF INTEREST RATES



Source: Gurkaynak, Sack & Wright (2006), Kim & Wright (2005), Adrian Crump & Moench (2013), Engstrom & Sharpe (2019), QTC Economic Research

Second, I ran a version of the models that excluded the period were interest rates were at the Zero Lower Bound. This was done as the Federal Funds Rate being close to zero could distort the model's parameter estimates given the proximity of short-term yields to zero [Johansson & Meldrum (2018)]. This adjustment did not meaningfully change the models' estimates, which suggests the parameter estimates were unaffected by including the period in which rates were close to zero.

GRAPH A4: COMPARISON OF ESTIMATES INCLUDING AND EXCLUDING PERIOD WHEN RATES AT ZERO LOWER BOUND



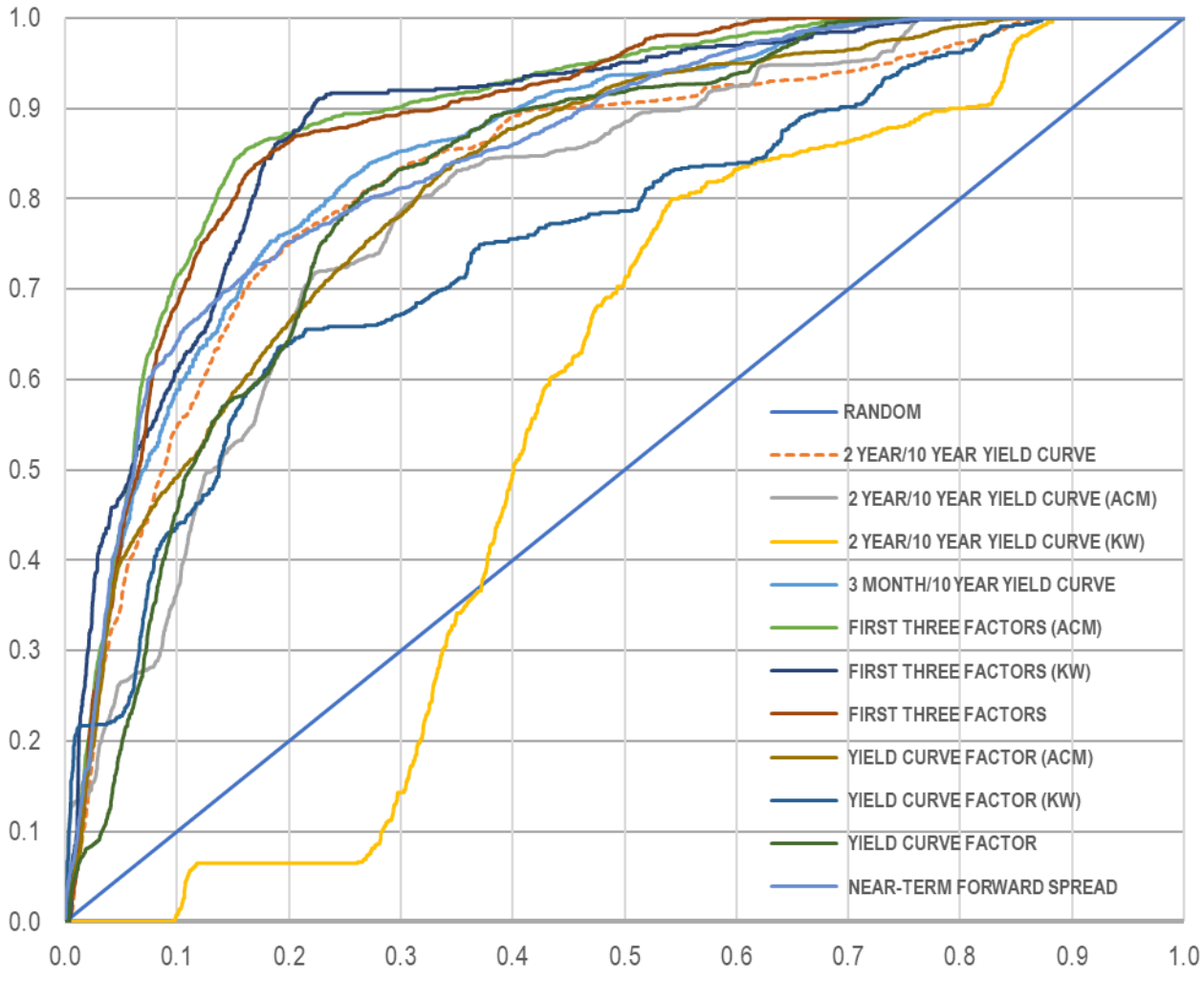
[1] These are the bottom three items in Table A2

Section A4: Forecast accuracy of different yield curve-based measures

Receiver Operator Curves (ROC) can be used to assess the accuracy of forecasting models which assess the probability of a binary event (in this case, the probability of there being a recession or not). A short and simple explanation of ROC can be found in Miller (2019). The better forecasting models are those which maximise the area under the ROC. For example, a model that perfectly predicts recessions will result in a line that traces along the left and top axes. On the other hand, a random 'coin-flip' approach to predicting recessions will result in the straight light blue line in Graph A5. A model that has some predictive power will have a curve that lies somewhere above the random benchmark.

This analysis suggests that the 2-year/10-year yield curve is middle of the pack when it comes to how accurately it forecasts recessions. The most accurate measures are those based on the first three principal components of the yield curve, consistent with Johansson & Meldrum (2018) and Miller (2019). The 3-month/10-year is then most accurate, consistent with Wright (2006), Liu & Moench, 2014 and Bauer & Mertens (2018b).The Near-term Forward Spread is the other measure more accurate than the 2-year/10-year, consistent with Engstrom & Sharpe (2022). The relative accuracy of the different yield-curve based measures can be seen in Graph A5.

GRAPH A5: RECEIVER OPERATING CURVES FOR DIFFERENT YIELD CURVE-BASED RECESSION PROBABILITY ESTIMATES



Source: QTC Economic Research

Section A5: Other measures to use to generate recession probability estimates

Several market-based measures, independent of the yield curve, were combined to 'nowcast' recession probabilities. These are set out below.

TABLE A3: SERIES USED IN CONSTRUCTION OF MARKET-BASED MEASURE OF RECESSION PROBABILITIES (APART FROM YIELD CURVE)

Series	Frequency	Source
Expected default rates	Monthly	Gilchrist & Zakrajšek (2012)
Excess Bond Premium	Monthly	Gilchrist & Zakrajšek (2012)
S&P 500 Real Price-Earnings Ratio	Monthly	Robert Shiller
Financial Uncertainty	Monthly	Jurado, Ludvigson & Ng (2015)
(Adjusted) Financial Conditions Index	Weekly	Federal Reserve Bank of Chicago via Bloomberg
Financial Conditions Index	Daily	Goldman Sachs via Bloomberg

Similarly, several macroeconomic series were combined to 'nowcast' recession probabilities. These are set out below.

TABLE A4: SERIES USED IN CONSTRUCTION OF FUNDAMENTAL-BASED MEASURE OF RECESSION PROBABILITIES

Series	Frequency	Source
Sahm Rule Recession Indicator (Real-time)	Monthly	Federal Reserve Bank of St Louis
Cycle component of Brave-Butters-Kelley Index of Monthly GDP growth	Monthly	Federal Reserve Bank of Chicago
Macro Uncertainty	Monthly	Jurado, Ludvigson & Ng (2015)
Aruoba-Diebold-Scotti Business Conditions Index	Daily	Federal Reserve Bank of Philadelphia

As the series in Tables A3 and A4 are available at different time intervals and given a desire to have high frequency estimates of recession probabilities, a mixed frequency approach was used to generate daily 'nowcasts' of the monthly recession probability indicator from the New York Federal Reserve. This indicator assesses recession probabilities based on the 3-month/10-year yield curve and, as per this recent note from researchers at the San Francisco Federal Reserve, indicates a much lower probability of a recession at present relative to the 2-year/10-year yield curve. A variation of this Mixed Data Sampling (MIDAS) approach was used in a previous note with details available in its technical appendix.