YIELD CURVE INVERSION AS A PREDICTOR OF RECESSIONS AND OTHER ECONOMIC FACTORS

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Abstract

The yield curve inversion is an economic phenomenon that has long been attributed as a strong predictor of financial hardship and recessionary times. In fact, every recession except one since 1955 has been preceded by a yield curve inversion. That accuracy is off the carts, especially in the world of financial prediction. So how does it happen? Typically, a normal yield curve slopes upwards, meaning that holders of long-term debt instruments have higher yields than their shorter-term counterparts because they have assumed more risk. When the yield curve inverts, however, shorter-term maturities provide higher yields than long-term debt. This means investors view short-term debt instruments as far riskier than long-term bonds. To measure how the yield curve inversion affects the economy, this paper measures the monthly and daily data of two Treasury curve spreads against the S&P 500, Dow Jones, the industrial production index, and the unemployment rate. The findings of this paper establish that the yield curve inversion is a strong indicator, rather than predictor, of recessions using a wavelet analysis and time-series approach.

KEYWORDS: (*Yield Curve Inversion, Recession, Wavelet Analysis*)

JEL CODES: C10, G1

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Signature

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Introduction

If one could predict the future, what would they do with their newfound knowledge? The possibilities are seemingly endless without direction, which is equally intriguing and terrifying.

Within the world of finance, banking, business, and the broader United States economy, it has long been understood that it is impossible to predict the future success of an investment with full certainty. Rather, the entire U.S. financial industry, which has generally thrived since World War II, is built on assumptions.

Unfortunately, throughout history, every economy has experienced periods of both positive and negative growth. It is an inevitable trait of markets. Supply and demand shift as consumer preferences change. Confidence is a powerful tool that can swing either way. During periods of growth, consumers and investors are confident, willing to spend, and more likely to take risks. This leads to increased demand, flow of money, credit, investments, production, profits, jobs, and more. On the other hand, rougher economic times come with populations being more conservative. Investors pull out of riskier equities, the average citizen consumes less, and businesses reflect decreased production, revenue, and an increase in unemployment.

These periods are usually referred to as a recession, defined as a decline in Gross Domestic Product in two consecutive quarters (6 months). For public companies, this usually means a sharp decline in stock prices as well as inventory, investments, number of employees, and sales. Private companies, family-owned shops, and other smaller stores experience the same hardship, and many will cut costs in the manner. Although times of economic slowdown are inevitable, there are trends that, throughout history, have strongly suggested that rougher times are ahead.

Arguably one of the strongest indicators of a financial recession throughout history has been the yield curve inversion (Bauer & Mertens, 2018; Burgess, 2019; Cwik 2004-05; Estrella & Mishkin, 1996; Estrella & Trubin, 2006; Haubrich & Dombrosky, 1996; Wright, 2006). Every recession except one since 1955 has been preceded by one. How can an economic occurrence have such accuracy?

The Yield Curve

Healthy yield curves slope upwards reflecting future growth, increased activity, and inflation. On the other hand, downward-sloping curves indicate potential future economic decline (Burgess, 2019). The yield curve itself is a graphical representation of yields on similar bonds across a variety of maturities, also known as the term structure.

Typically, the yield curve slopes upward, reflecting that holders of long-term debt instruments have higher yields than their short-term counterparts, because they have taken on more risk. Investors also demand higher yields to compensate for the opportunity cost of investing in bonds versus other asset classes and to maintain an acceptable spread over inflation rates.

When the yield curve inverts, however, shorter-term maturities provide higher yields than long-term debt. The yield curve becomes negative, implying that short-term debt instruments are riskier than long-term ones, as higher risk is associated with higher yield. The risk being that the bond issuer defaults on their debts and cannot pay back principal and interest. Investors see long-term yields as an acceptable substitute for the potential of lower returns in equities and other asset classes, which tend to increase bond prices and reduce yields in the long term.

Figure 1.1: The yield curve

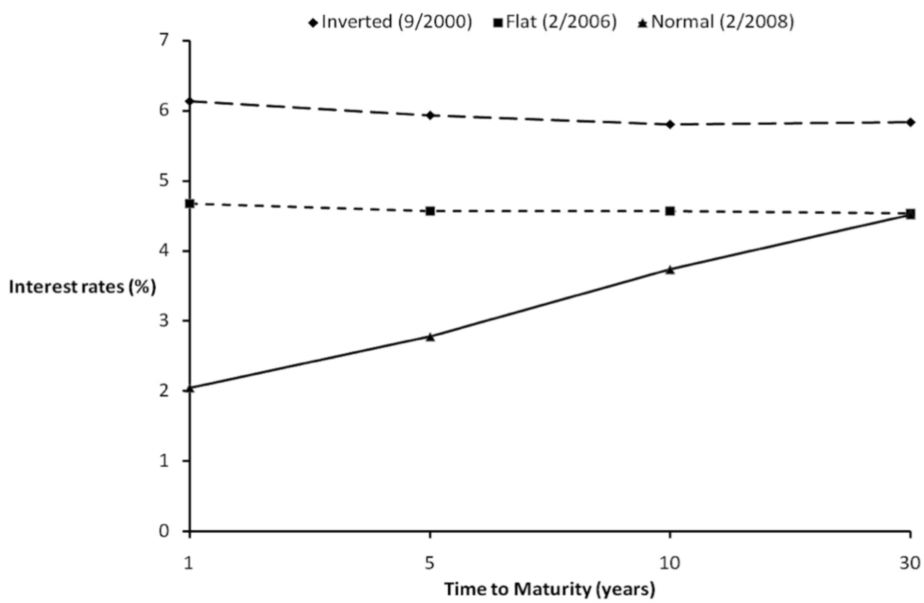


Figure 1 Normal, flat, and inverted yield curves

Source: Zaloom (2009)

Explained in another light, the inversion happens when long-term interest rates drop below short-term rates, or the cost of borrowing is higher now than in the future. This unusual occurrence indicates that investors are moving their money away from short-term bonds and into longer-term ones, usually associated with a recession. Such a pessimistic view has a ripple effect, and with millions of investors, both domestic and foreign, as well as an interconnected global economy, consequences can be disastrous as seen in 2008.

This Paper

During recessions, economic factors such as the broad stock market indices, industrial production, and employment also decrease with GDP. These factors are indicative of the health of the economy and will be tracked in the following study.

Is the yield curve inversion a strong predictor of recession and economic decline? Or is it an inevitable occurrence, like declines in the markets, production, and employment, which tend to happen with simultaneous decreases in GDP? To measure, the data will be portrayed using the time series methodology, which tracks data points indexed in time order.

This study is of utmost importance for multiple reasons. Firstly, yield curve inversions and two consecutive quarters of GDP decline happened in 2022. Concerns of a recession have been growing throughout the second and third quarters of the fiscal year. Second, it is among the first of studies regarding yield curve inversions in the post-pandemic era. A 2019 inversion preceded the 2020 financial disaster, although COVID-19 played the largest factor. As the United States attempts to recover and transition, additional inversions occurred in 2022 amid larger concerns for a pending recession. Third, the study synthesizes the consensus of previous literature into one. It is expected that the yield curve inversion is a strong *indicator*, rather than predictor, of recessions. The study also includes other major measurements of economic health like stock markets, industrial production, and employment.

Therefore, the central question of this study should be revised. To what degree is the yield curve inversion an accurate indicator of recessions and subsequent declines in stock market indices, industrial production, and employment? The expected finding of the paper is that yield curve inversions are among the most reliable and accurate indicators of recessions and overall economic decline.

Literature Review

Any trigger can cause the yield curve to invert, whether that be a foreign conflict, an oil crisis, a dotcom bubble, a housing crisis, a pandemic, or the following inflationary period. What happens in the following months determines the outcome at hand.

Throughout previous literature, it has been well-documented that recessions occur within two years of a yield curve inversion. It is commonly accepted that the 10-Year Treasury Note minus the 3-Month Treasury Bill (10Y3M hereafter) is the best measure of yield curve inversion when attempting to predict future economic events (Bauer & Mertens, 2018; Burgess, 2019; Cwik 2004-05; Estrella & Mishkin, 1996; Estrella & Trubin, 2006; Haubrich & Dombrosky, 1996; Wright, 2006). It has substantial predictive power and provided the best forecast of real growth four quarters into the future (Haubrich & Dombrosky, 1996). The 10-Year Treasury Note minus the 2-Year (10Y2Y hereafter), as well as the Federal Funds Rate, (10YFF), are also identified as potential strong predictors of recessions. (Bauer & Mertens, 2018).

Support for the Yield Curve Inversion

The simplest theoretical rationale for why term spreads might be a useful leading indicator, Jonathan Wright explains, is that by neglecting term premiums, the term spread measures the difference between current short-term interest rates and the average of expected future short-term interest rates over a long horizon. Therefore, the term spread is a measure of the stance on monetary policy relative to long-run expectations. The higher the term spread, the more restrictive current monetary policy is, and the more likely a recession over subsequent quarters (Wright, 2006).

Probit models are among the most used in previous literature, and all the studies are in a time series methodology by logic and nature. A time series analysis by Neil Karunaratne in 2002 examines the prediction of economic growth and recession using the yield curve in Australia. He utilizes a probit model estimated by maximum likelihood methods. The slope of the yield curve outperforms other financial indicators such as the stock market, money base, and the leading indicator, as a predictor of economic activity over forecast horizons of about one year (Karunaratne, 2002).

Arturo Estrella and Frederic Mishkin examine the yield curve in their study as an accurate indicator and strong supplement to other forecasting models. The analysis differs from earlier studies in that they chose out-of-sample performance, looking at the accuracy in predictions for quarters beyond the period over which the model is estimated. They use the probit model, which relates to the probability of being in a recession to a specific explanatory variable such as the yield curve spread. One of their most successful models estimates the probability of a recession four quarters into the future as a function of the current value of the yield curve spread between the 10-Year Treasury Note and 3-Month Bill. The biggest findings were that the yield curve remains a strong probability forecaster of recessions between two and six quarters, and it can supplement econometric models as a valuable forecasting tool (Estrella & Mishkin, 1996).

Estrella repeated the study in 2006 with Mary Trubin, arriving at many similar conclusions. They used a time series approach to gather the Treasury spread and recession data from the National Bureau of Economic Research. They sought to construct a model that translated the steepness of the yield curve into the likelihood of a recession. Their probit equation uses the normal distribution to convert the value of a measure of yield curve steepness into a probability of recession one year ahead. There were no additional major findings from the previous study. 10Y3M rates are the most accurate forecasts of recessions. They contend that predictive power is statistical, and regardless of the accuracy of past signals, it is impossible to guarantee future results. (Estrella & Trubin, 2006).

Paul Cwik presents the best argument as to why the yield curve inverts one year before a recession. He uses a capital-based macroeconomic model to trace out the effects of an injection of short-term working capital. This creates malinvestments by households, entrepreneurs, and businesses in both the short and long term and is eventually unsustainable. The assumption is made that capital injection transforms into fixed capital, long-term projects, and early-stage malinvestments. If inconvertible, the liquidation process is even more severe. Monetary injections, taking the place of periods of economic growth, lead to a disequilibrium between households and entrepreneurs. Monetary injections steepen the yield curve which falsely signals entrepreneurs to begin new investments and encourages households to increase their demand for final goods and services. This results in unstable malinvestments which raise prices and lead to a credit or resource crunch. In attempts to prevent their projects from being liquidated, entrepreneurs will cause the yield curve to flatten or invert as they scrap for any equity they can get. Cwik argues that other models over-aggregate and are unable to recognize that the root cause of the inversion is the malinvestments (Cwik, 2005).

Against the Yield Curve

The opposing side to the yield curve as a strong predictor is the study by Joseph Haubrich and Ann Dombrosky in 1996. The article is unique from all the others because it documents the decline in the yield curve's predictive ability between 1985 and 1995. Their model is designed to predict real GDP growth four quarters into the future based on the current yield spread. They regress real GDP against an index of leading economic indicators, its own lag, the 10Y3M spread, and forecasts from the Blue Chip organization and DRI / McGraw-Hill. They concluded that the 10Y3M spread was the best forecast of real growth four quarters into the future for the previous 30 years but was the worst forecast in the previous 10 years. They hypothesize a rolling regression model or more lags could improve yield curve performance.

Consensus

The overall conclusion of the literature review is that inverted bond yield curves have accurately preceded recessions, but not necessarily predicted them. Correlation does not equal causation, as the inversion tends to happen before the recession following a major shock or change to the aggregate economy. Various models, equations, regressions, and methods have been used in previous literature; however, they all sought to identify a similar answer – whether yield curve inversions are strong predictors of recessions. Perhaps the issue should be refined to whether inversions are strong *indicators*, not predictors, of recessions to come. Because the data set is essentially the same for every study, the findings should be objective and simple. Yield curves, shocks, GDP, markets, production, and employment are all easily trackable over time, with no subjectivity involved.

The contribution of this study is an updated, big-picture approach, synthesizing the conclusions of many authors who have sought to answer the same question. This study is unique from the others, however, in multiple ways. Firstly, it utilizes wavelet analysis which has not occurred commonly throughout existing literature. Second, the 10Y2Y has inverted multiple times throughout 2022. Third, with access to the most recent yield curve data and literature, this work provides the most updated and well-rounded approach to the question, "Are yield curve inversions strong indicators of recessions?"

Methodology

The time series approach captures a series of data points indexed in time order. Since financial data is trackable over a long period of previous history, this is the most common method due to the logistics of the analysis. Yield curves, stock market prices, production numbers, and employment are all trackable in frequent, chronological order.

Explained differently, a time series data is the data on a response variable (Y[t]) observed at different points in time *t*. Data is collected chronologically at regular intervals. This study uses daily data from Treasury yields and stock markets, as well as monthly data for yields, markets, industrial production, and unemployment, to forecast recession predictions. The aim of forecasting time series data is to understand how the observations will sequence in the future. This study will focus on the application of the wavelet method and wavelet coherence to see the co-movement between Treasury yields and the other economic variables.

Wavelets

Wavelets explain the relationship between variables with respect to time and frequency. They are rapidly decaying wave-like oscillations that have zero mean, finite duration, and come in different sizes and shapes with two important concepts: scaling and shifting. Scaling is the process of stretching or shrinking the signal in time. Shifting is the delaying or advancing onset of the wavelet along the length of the signal – the wavelength is shifted until it aligns with the feature that is sought in the signal.

In the context of the 10Y3M or 10Y2Y Treasury spread, data points are scaled or shifted in a given time period to match identical drops or increases in data points for stock market indices, production, and employment in the same period. The function below is the official notation of a wavelet where *s* represents the scale of the wavelet, *t* is time, *u* represents the location, and 1 over the squared root of *s* being the factor of normalization.

$$\psi|t| = \frac{1}{\sqrt{s}}\psi|\frac{t-u}{s}| \tag{1}$$

Building off this, the "continuous wavelet transform" maps out a range of individual wavelets, locations, and scales, with notation from Kristoufek (2015).

$$W_x(u,s) = \int_{-\infty}^{+\infty} \frac{x(t)\psi^*\left(\frac{t-u}{s}\right)dt}{\sqrt{s}} \tag{2}$$

From here, the study is enabled to create a cross-wavelet transform and wavelet coherence. To compare two-time series data, the continuous wavelet framework can be generalized to perform a cross-wavelet transform with:

$$W_{xy}(u,s) = W_x(u,s)W_y^*(u,s) \tag{3}$$

The continuous wavelet transform of the two times series (X[t]) and (Y[t]) are used and the * represents a complex conjugate, resulting in the cross-wavelet power

(Kang et al., 2019). This is used to find covariance localized in the time-frequency space of the two series (Kristoufek 2015).

This study, however, utilizes wavelet coherence, rather than covariance, for the final figures by following Terrence and Webster (1998), who define coherence as:

$$R^2(u,s) = \frac{\left|S\left(s^{-1}W^{xy}(u,s)\right)\right|^2}{S\left(s^{-1}\left|W^x(u,s)\right|^2\right)S\left(s^{-1}\left|W^y(u,s)\right|^2\right)} \tag{4}$$

S is a smoothing operator and a scale (Kang 2019). The wavelet squared coherence (R^2) results in values between 0 and 1, with values closer to 1 representing strong co-movement and 0 being a weak relationship. To further account for an observable relationship (squared coherence can interfere), a phase difference described by Terrence and Compo (1998) should be applied, which results in the final equation:

$$\Phi_{xy}(u,s) = \tan^{-1}\left(\frac{\Im\left\{S\left(s^{-1}W^{xy}(u,s)\right)\right\}}{\Re\left\{S\left(s^{-1}W^{xy}(u,s)\right)\right\}}\right) \tag{5}$$

The *I* and the *R* represent imaginary and real parts of the smoothed cross-wavelet power. The phase of the relationship is represented by black arrows on the wavelet coherence spectrum plots. The right-pointing arrows indicate an in-phase or a positive correlation and the left or the out-of-phase represents a negative correlation. When in the in-phase, arrows pointing upwards represent a leading (X[t]), while downwards-facing arrows represent a leading (Y[t]). When the relationship is out-of-phase, the situation works vice versa.

This Paper

The first hypothesis of the study is that yield curve inversions are extremely reliable indicators, rather than predictors, of recessions. The latter implies a cause-and-effect relationship that is too complicated to analyze in real time. There are endless points that play into recessions and different factors are emphasized at different times. For example, the oil crisis which preceded the 1980s recession, the dot com bubble which occurred around the 2001 recession, the housing crisis leading to the 2008 disaster, and a yield curve inversion, followed by a global pandemic, leading to a possible recession in 2022 and beyond. While the former in each scenario certainly played a role in the following periods of economic decline, there are many other factors in play, like employment, production, trade, conflict, and investor confidence. However, none of these occurrences can be solely credited for causing recessions. They are events with negative economic connotations that tend to precede recessions.

To demonstrate how yield curve inversions imply future volatility, this study will use the 10Y3M and 10Y2Y Treasury data to show expected volatility in the S&P 500 index, Dow Jones index, Industrial Production, and Unemployment.

Consider the following two models, supporting the first hypothesis of the study. For simplicity's sake, each equation below assumes that the 10Y3M is being measured against the S&P 500 index monthly data, exclusively.

$$\Delta\%(10Y3M)_t = \alpha 0 + [(0) * \alpha 1 \Delta\%(SP500)_t] + \varepsilon_t \quad (6)$$

The above function represents the impossible scenario that a percent change in the 10Y3M equals an exactly zero percent change in the S&P 500. Therefore, this is just for reference. The equation below represents the main hypothesis of this study and implies a situation where any relationship exists. A given percent change in the 10Y3M results in an *N* percent change in the S&P 500, where *N* represents any amount of percent change in the S&P 500 as a response to changes in the 10Y3M. Any significant change can be attributed to the 10Y3M or 10Y2Y being a strong *indicator* of recessions with respect to each independent economic variable measured in this study.

$$\Delta\%(10Y3M)_t = \alpha 0 + [(N) * \alpha 3 \Delta\%(SP500)_t] + \varepsilon_t \quad (7)$$

The second hypothesis of this paper is that yield curve inversions are indeed very strong indicators of recessions (as opposed to weak indicators) that tend to occur before economic decline at an extremely high rate. Every recession since 1955 except one has been preceded by a yield curve inversion.

Using the 7^{th} equation (above), the study expects to see similar changes in the bivariate model. In plain text, a strong, positive change in the 10Y3M would indicate an expected strong, positive rise in the S&P 500, and vice versa with negative changes. The study expects all variables to move together except for wavelet analyses that include unemployment (in this case, they move opposite directions).

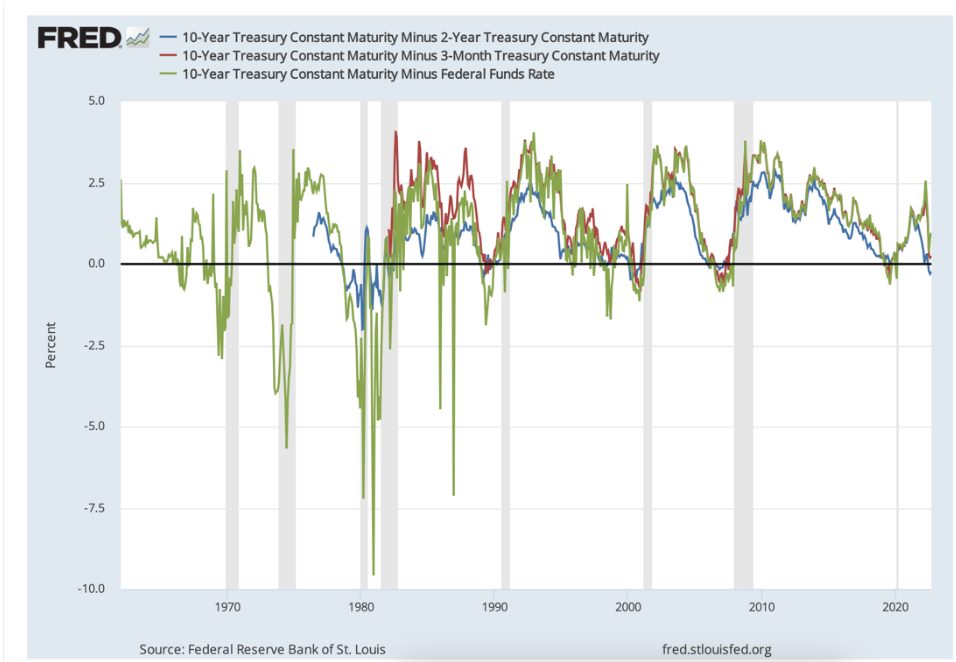
Specifically, the S&P 500 monthly and daily data, dating back to 1992, will be measured against the 10Y3M's monthly and daily data, respectively. The Dow Jones is measured in the same way as the S&P 500. Industrial Production and Unemployment are measured back to 1982 and include both the 10Y3M and 10Y2Y for the monthly data only (daily data was excluded for these two variables for simplicity).

Context

There are four general time periods measured in this study. Three are commonly accepted recessions, 1980 (for the variables that go back that far), 2001 and 2007-08. Available data does not enable the study to extend further back. The third stretch, 2020-22, will be treated as a recession although it has yet to be officially defined as one. Yield curve inversions in 2019 and 2022, as well as a rising rates environment to combat inflation (which is visualized when the yield curve inverts), overwhelmingly support the notion that late 2022 and 2023 can be recessionary time periods.

For economic context and visualization, a graph of the 10Y3M and 10Y2Y, as well as the 10YFF, has been included below. Time periods that have been designated as recessions are shaded in dark grey. When the linear trends dip below 0.0 percent, the yield curve has inverted. The Federal Funds rate will not be included in this study's analysis because all the term spreads follow a similar pattern. Additionally, this measurement displays more volatility than the other two. To keep efficiency and consistency with previous literature, this will be excluded from the official analysis.

Figure 3.1: 10-Year Treasuries Minus 3-Month, 2-Year, and Federal Funds



Units: percent

Source: Fred.stlouisfed.org

The Federal Reserve Economic Data (FRED hereafter) and Yahoo Finance provided all necessary data collection. Two descriptive statistics graphs were created from the datasets.

Table 3.1: Monthly Descriptive Statistics

Variable	Observations	Mean	Median	Min	Max
10Y3M	489	1.73	1.71	-0.70	4.15
10Y2Y	489	1.043	0.97	-0.41	2.83
Unemployment	489	6.12	5.70	3.50	14.70
Industrial Production	489	82.74	90.47	46.98	105.18
SP500	369	1,564.80	1,281.70	403.69	4,766.18
Dow Jones	369	13,494.00	10,883.00	3,226.30	36,338.30

The monthly descriptive statistics graph includes all variables in this study, aggregated on an average basis. For the S&P 500 and Dow Jones, data begins on February 1, 1992 for the monthly data (the next recorded data point took place on 3/1/92, then 4/1/92, and so on). For the Unemployment and Industrial Production (as well as 10Y3M and 10Y2Y) variables, monthly data begins on January 1, 1982.

The 10Y3M denotes the 10-Year Treasury Minus the 3-Month, as stated earlier, which implies that negative values equal yield curve inversions. This is the same for the 10Y2Y. Unemployment, also given as a percentage, reflects the unemployment rate (ratio of unemployed to the labor force) in the United States every month or day since 1982. During recessions, unemployment rises as businesses cut costs and "unessential" roles. Therefore, it is hypothesized that when the yield curve inverts, recessions are to follow, and during recessions, unemployment rises.

Industrial production and the two stock market metrics are measured as real indexed units (If the S&P 500 opened the month or day at 1,500, this is the value recorded in the dataset). Industrial production is measured because it is one of the largest and most important industries in the economy. In response to any rising costs of raw materials, businesses cut jobs and production, and manufacturing activity decreases. This inevitably affects various markets within the S&P 500 and the Dow Jones. All of the variables are intrinsically linked within the United States economy. Additionally, the Dow Jones is intrinsically industrial-focused, making it a strong suitor and complement for the Industrial Production variable.

The Treasury yields, in line with the FRED graph above, have followed a similar trend over the past thirty years. The 10Y3M has the higher mean and the lower minimum value (meaning the difference between the 10-Year and the short-term rate was the most drastic at the 10Y3M mark, as opposed to 10Y2Y). In context, most literature has determined the 10Y3M as the most accurate measurement.

Table 3.2: Daily Descriptive Statistics

Variable	Observations	Mean	Median	Min	Max
10Y3M	7762	1.70	1.64	-0.95	3.87
SP500	7762	1,563.00	1,281.80	394.50	4,796.56
Dow Jones	7762	13,487.00	10,913.00	3,137.00	36799.65

The daily data excludes the unemployment rate and industrial production variables and begins on February 1, 1992 (following data entries are 2/2/1992, 2/3/1992, etc.). Treasury yields do not differ drastically from the monthly data as expected. The number of observations varies more so than the monthly data, an expected occurrence given the frequency of data.

Every observation in the descriptive statistics tables above uses raw data. However, for this study's analyses (explained in Results and Analysis), additional adjustments are made. All units for Treasury yields, as well as the unemployment variable, are measured in percentages. The S&P 500, Dow Jones, and industrial production are measured on an indexed-unit basis. The averages for unemployment, industrial production, the S&P 500, and the Dow Jones are benchmarks – upon yield curve inversions and a recessionary period, this study expects to see drops below the mean for these variables. Because a yield curve inversion has happened before every recession since 1980, and subsequent drops in the S&P 500 and Dow Jones occur in every recession since 1980, it is safe to say that yield curve inversions have also preceded the drops in the broad stock market indices during recessionary periods. While not a causation relationship, yield curve inversions do occur before recessions, and recessions usually mean declines in stock markets. To follow are declines in employment and production.

The first expectation of this study is to see the yield curve invert prior to recessions. The yield curve has been inverted in this study when the 10Y3M or 10Y2Y values are negative. When this is displayed, the next expectation is to see declines in stock market indices, industrial production, and unemployment. These are also expected to have declining periods during recessions. With yield curve inversions occurring before recessions, and recessions leading to declines in the other factors, it is assumed that yield curve inversions remain strong indicators that recessions and overall negative economic decline will occur.

Results and Analysis

Although the descriptive statistics above contain raw data, the actual wavelet analysis took the natural log of the change from the "previous" to "current" measurement. This is how the model accounts for a yield curve inversion in a time series, wavelet analysis.

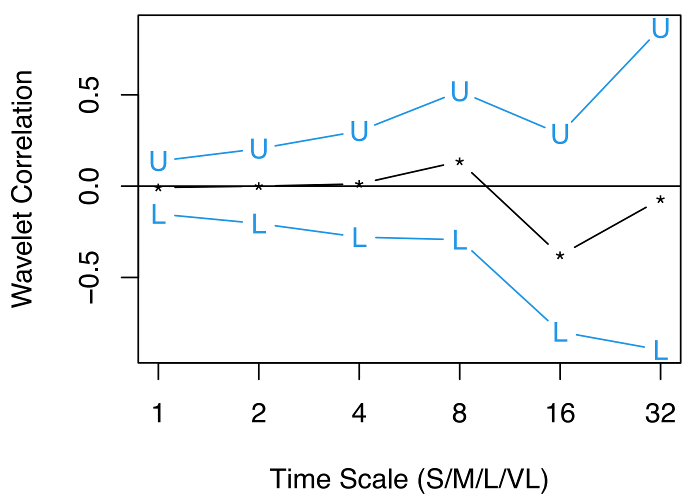
Two figures are provided for each measurement of interest. The first is a correlation table, displaying the relationship between the two variables at hand. On the X-axis is the wavelet scale, which tracks time periods in months from the first data entry (either 2/1/1992 or 1/1/1982). Any point between one and four is defined as the short-term future (S), four to eight as the middle-term future (M), eight to sixteen as the long run (L), and sixteen to thirty-two as the "very" long run (VL).

Upon the transition from the correlation figure to the wavelet analysis, the X-axis is moved to the Y-axis, and the new X-axis becomes the time period in units from the first observation, in either months or days. The 0.0-1.0 scale on the right of the wavelet analysis explains the strength of the relationship between the variables of interest (areas with yellow, orange or red explain a strong correlation and are therefore of interest to the study.

Additionally, any data within the solid, black outlines represent significant results at the 0.05 level (these areas generally have the highest correlations as well). Arrows within these black outlines explain the actual changes taking place. Arrows pointed to the right are labeled as positively correlated, and to the left as negatively correlated (under the condition that a significant correlation exists). Arrows pointed upwards and right, as well as downwards and left, are the foci of this study. The former indicates that volatility in the Treasury spread occurred before changes in the other variables (meaning that the yield curve inversion is a strong indicator of recessions). Left and down means a negative correlation between the Treasury spread and the other variable (SP500, Dow Jones, IP, or UE), with the Treasury volatility occurring before the others. Negative correlations imply that the variables move in opposite directions.

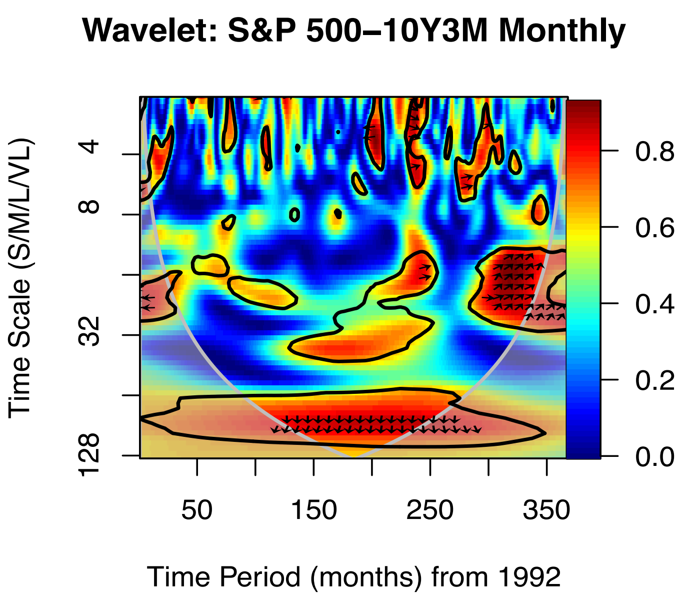
Monthly

Figure 4.1: S&P 500 10Y3M Monthly Correlation



In the short and medium run, correlation is expected to be about zero until dipping negative in the long and very long run. A negative correlation implies that an increase in one variable leads to a decrease in the other. In this case, a yield curve inversion actually leads to a stock market index increase in the long run, although this can likely be explained by the fact that over the very long run, stock markets (and every other variable in this study) have increased on an all-time graph in value regardless of what happens with the yield curve.

Figure 4.2: S&P 500 10Y3M Monthly Wavelet



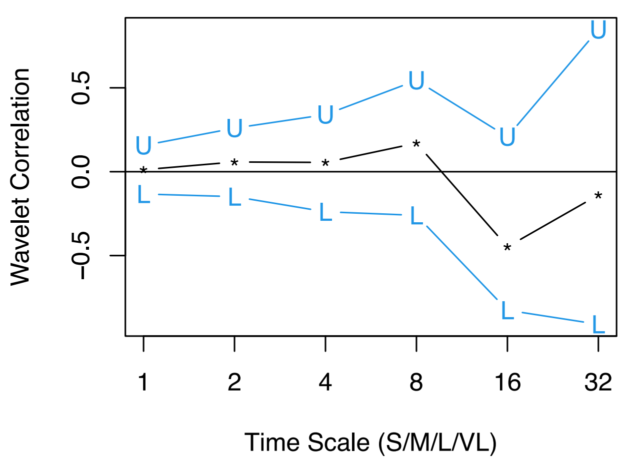
The very bottom row of arrows points directly downwards meaning it is too difficult to determine a correlation. There are three other areas of interest which overwhelmingly support the second hypothesis. In the year 2012 (250 months from 2/1/1992), there are blotches of strongly and positively correlated arrows (right) expected in the short term. It is difficult to determine which variable leads, but this evidence supports the claim that volatility in the yield curve leads to expected volatility in the S&P 500 in the short term, from a 2012 lens.

The most important area in this wavelet analysis is the outlook from 2020 (350), where in the medium-term future, volatility in the Treasury yield curve is expected to lead volatility in the S&P 500, with very high confidence. The correlation is the strongest of anywhere else on the wavelet "map," and the abundance of upward-and-right-pointing arrows suggest the yield curve leads the stock market index. Specifically, drops in the 10Y3M will precede drops in the stock market (and vice versa for rises) in the medium-term future from 2020. Refer to the table below to reference the Period on the X-axis and the specific date of that measurement.

Table 4.1: Time Period on Wavelet Graph and Date

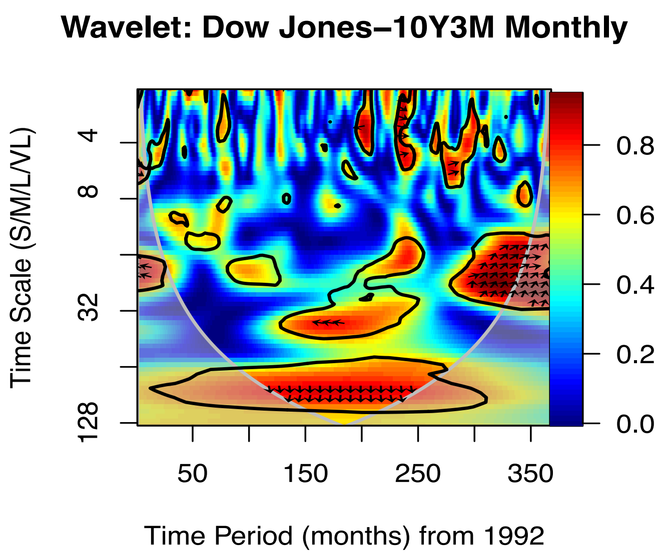
Period	Date
0	2/1/1992
50	4/1/1996
150	8/1/2004
250	12/1/2012
350	4/1/2020

Figure 4.3: Dow Jones 10Y3M Monthly Correlation



The correlation is weak and positive until the long term, then it becomes negatively correlated for the long and very long run future, similar to the S&P 500 measurement as expected.

Figure 4.4: Dow Jones 10Y3M Monthly Wavelet



Identical to the S&P 500 wavelet graph, the X-axis measures time periods from 1992 in months. The bottom area of data significance cannot be determined since the arrows do not definitively point left or right.

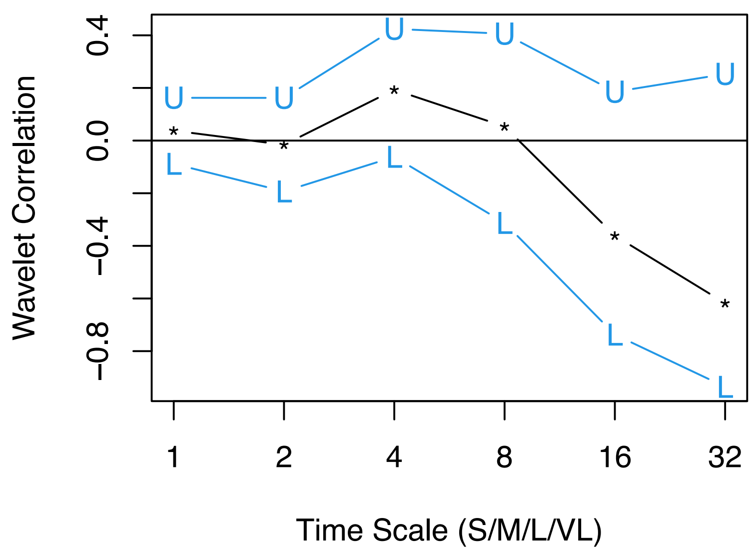
From a 2012 lens (250), there was an expected, strong correlation between the volatility of the yield curve and the Dow Jones index. However, it cannot be determined whether the correlation is positive or negative, and which variable lags behind the other.

Most interestingly is the 2020 lens (350), where there are very high and strong correlations between the Dow Jones and yield curve, with the 10Y3M expected to lead the Dow Jones in the middle-to-long term future.

Table 4.2: Time Period on Wavelet Graph and Date

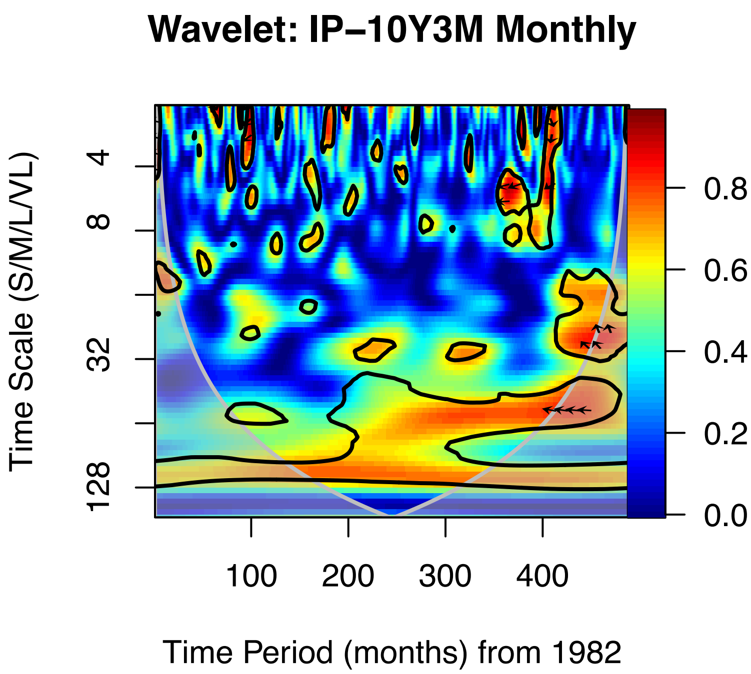
Period	Date
0	2/1/1992
50	4/1/1996
150	8/1/2004
250	12/1/2012
350	4/1/2020

Figure 4.5: Industrial Production 10Y3M Monthly Correlation



Industrial production appears to be positively correlated until the long run, where it drops and becomes negatively correlated at an increasingly stronger rate into the very long run.

Figure 4.6: Industrial Production 10Y3M Monthly Wavelet

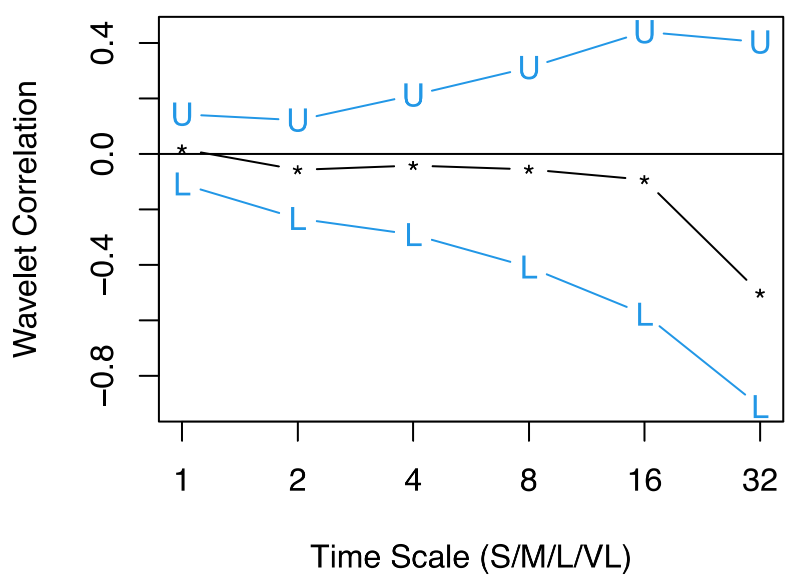


The Industrial Production, 10Y3M analysis does not provide enough evidence to make a confident, significant conclusion about the relationship between the volatility in IP and the Treasury spread. In the time period between 300-400 months following the first observation date, which would land around 2010, expected volatility in the short to medium term is expected. However, it is unclear which variable leads, and the lack of abundance of data points (arrows) suggest it is better to look somewhere else.

Table 4.3: Time Period on Wavelet Graph and Date

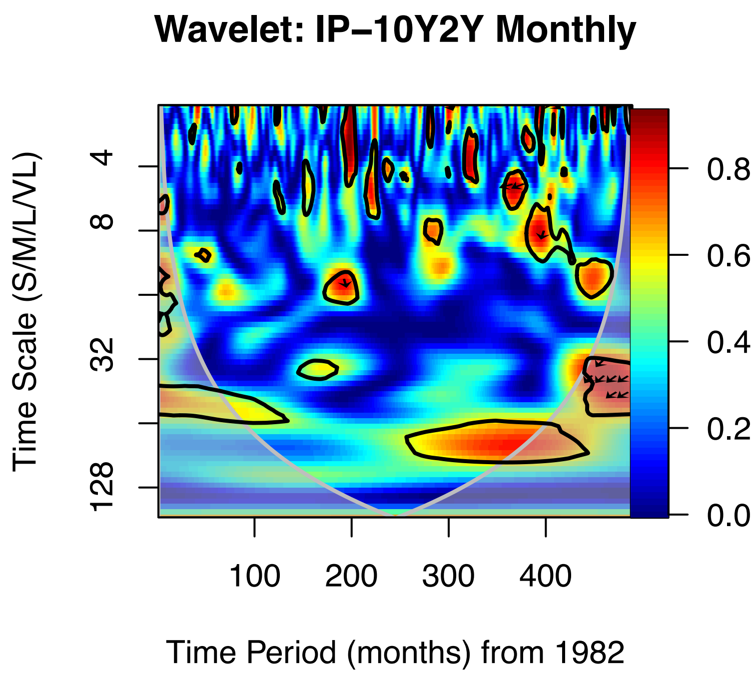
Period	Date
0	1/1/1982
100	5/1/1990
200	9/1/1998
300	1/1/2006
400	5/1/2014

Figure 4.7: Industrial Production 10Y2Y Monthly Correlation



Similar to the IP-10Y3M analysis, the IP-10Y2Y is negatively correlated at an increasing rate into the very long-run future.

Figure 4.8: Industrial Production 10Y2Y Monthly Wavelet

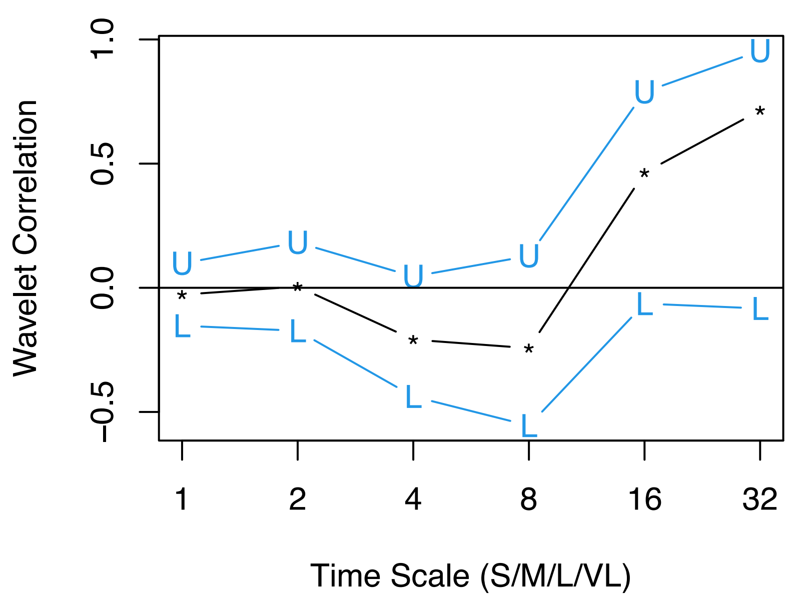


The Industrial Production, 10Y2Y analysis does not provide enough evidence to make a confident, significant conclusion about the relationship between the volatility in IP and the Treasury spread. In the 300-400 months following the first observation date, which would land around 2010, expected volatility in the short to medium term is expected. However, it is unclear which variable leads, and the lack of abundance of data points (arrows) suggest it is better to look somewhere else.

Table 4.4: Time Period on Wavelet Graph and Date

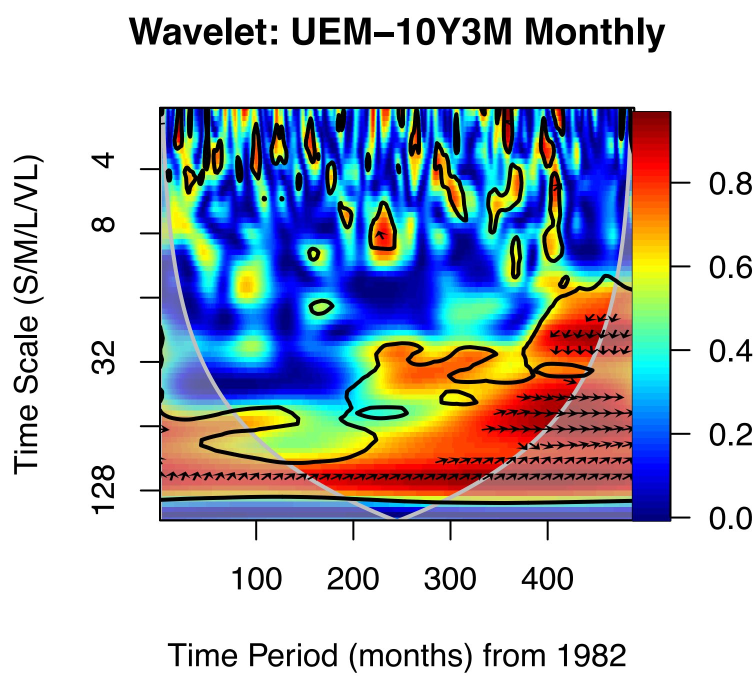
Period	Date
0	1/1/1982
100	5/1/1990
200	9/1/1998
300	1/1/2006
400	5/1/2014

Figure 4.9: Unemployment 10Y3M Monthly Correlation



The correlation between unemployment and the 10Y3M is the most intriguing graph thus far. In the short and medium run, the correlation is weak and negative before turning positive and becoming increasingly correlated into the long and very long runs. In the very long run, the correlation reaches the strongest (and positive) between any two variables in this study.

Figure 4.10: Unemployment 10Y3M Monthly Wavelet



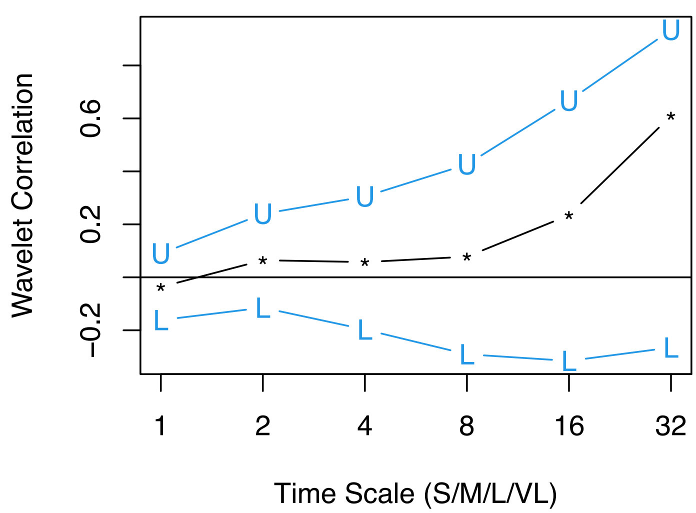
The largest area of interest is the bottom, central part of the wavelet graph with the abundance of upward-pointing, right arrows. Across 1998-2014 (200-400 months after 1/1/1982), volatility in the 10Y3M spread was expected to precede volatility in the unemployment rate. Specifically, positively correlated variables imply an increase in one leads to an increase in the other. This is surprising because the study expected yield curve inversions (a decrease in the 10Y3M) to lead to a higher unemployment rate (typical during recessions).

On the other hand, in the medium-run outlook from 2014 (400), the wavelet analysis displays an expected conclusion. The variables are strongly and negatively correlated with the Treasury spread leading to the unemployment rate. Essentially, a decline in 10Y3M leads to an expected increase in unemployment rate.

Table 4.5: Time Period on Wavelet Graph and Date

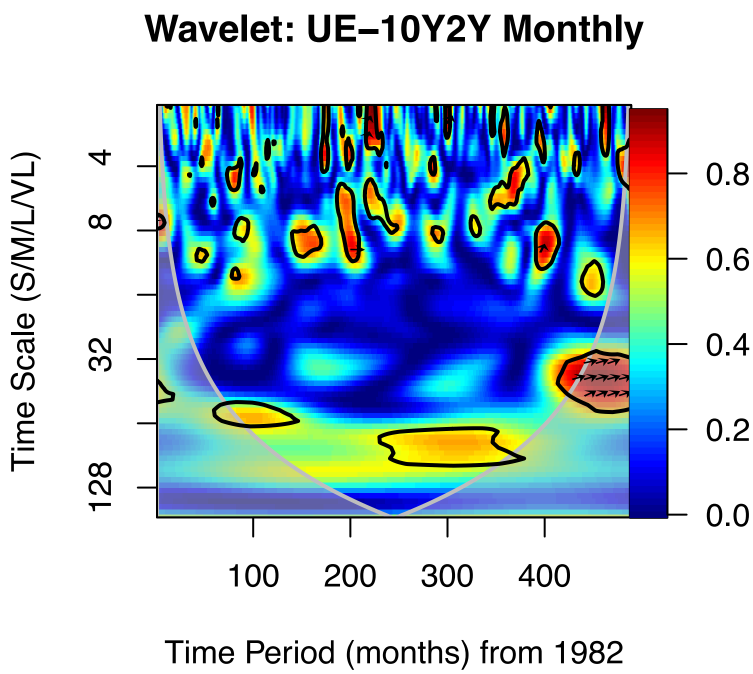
Period	Date
0	1/1/1982
100	5/1/1990
200	9/1/1998
300	1/1/2006
400	5/1/2014

Figure 4.11: Unemployment 10Y2Y Monthly Correlation



Unlike the 10Y3M spread's correlation with unemployment, the 10Y2Y displays almost no negative correlation which is surprising because the hypothesis expected a yield curve inversion to lead to an increase in unemployment (negative correlation). Rather, the relationship is positive and weak until the long run, where it increases.

Figure 4.12: Unemployment 10Y2Y Monthly Wavelet



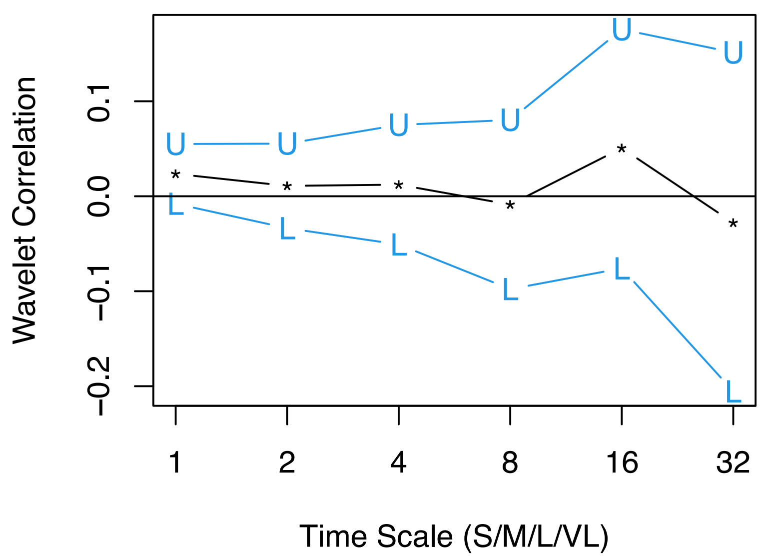
The wavelet analysis, however, does not show much support for a positive correlation between the two variables. Rather, it doesn't offer many conclusions at all. There are blotches of significant data but there are either no arrows or the data isn't inside the cone of influence, making it impossible to analyze.

Table 4.6: Time Period on Wavelet Graph and Date

Period	Date
0	1/1/1982
100	5/1/1990
200	9/1/1998
300	1/1/2006
400	5/1/2014

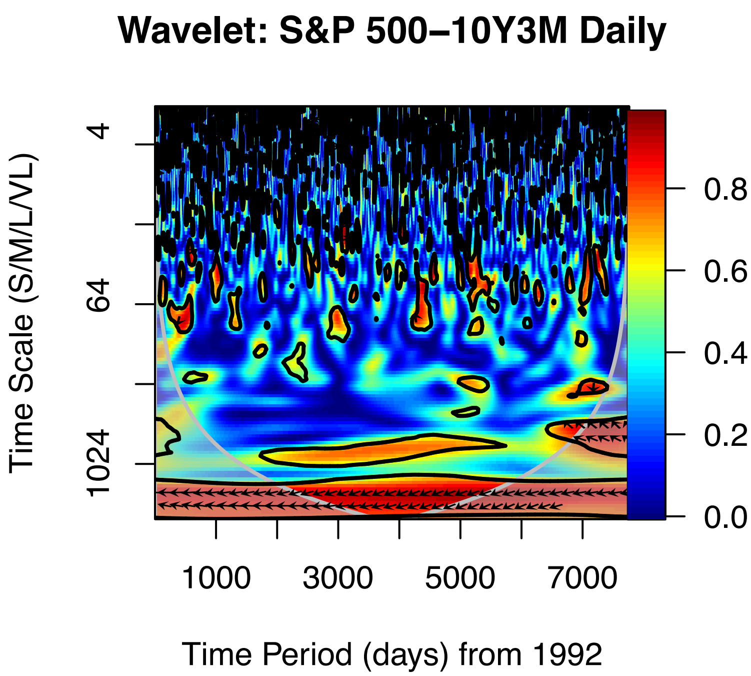
Daily

Figure 4.13: S&P 500 10Y3M Daily Correlation



There is no clear correlation between the S&P 500 and the 10Y3M daily data at any point in time.

Figure 4.14: S&P 500 10Y3M Daily Wavelet

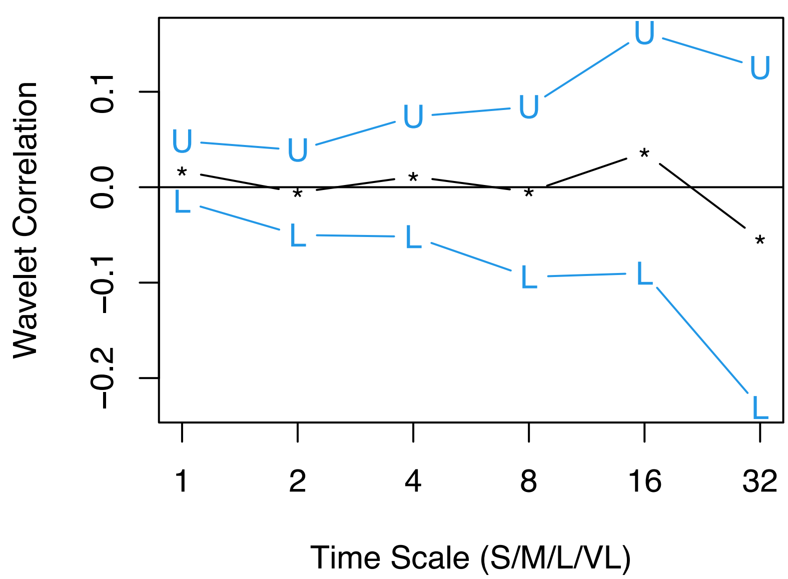


Due to the frequency of data, no significant outcomes can be concluded in the short to medium-term run. In the very long run, around 2000 to 2005 (~3000 to 5000 days from 2/1/1992), arrows point to the left (negative correlation) and slightly downwards, indicating that declines in the yield curve value were expected to occur before declines in the stock market from a long-term perspective.

Table 4.7: Time Period on Wavelet Graph and Date

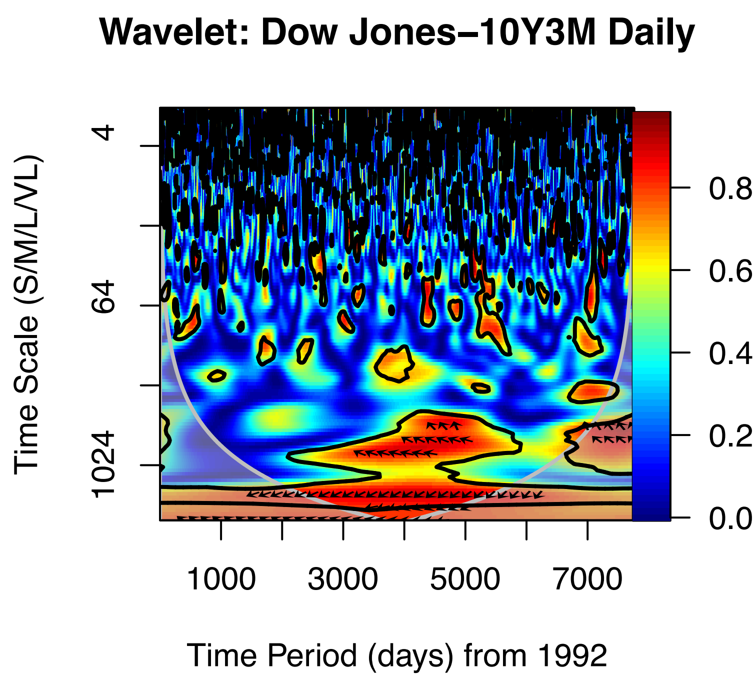
Period	Date
0	2/1/1992
1000	10/28/1994
3000	4/19/2000
5000	10/10/2005
7000	4/2/2011

Figure 4.15: Dow Jones 10Y3M Daily Correlation



Like the S&P 500, 10Y3M daily correlation, the values above remain too close to zero to determine a positive or negative correlation between the Dow Jones daily and 10Y3M daily.

Figure 4.16: S&P 500 10Y3M Daily Wavelet



Due to the frequency of daily data entries, it is too difficult to determine any conclusions in the short run. However, there is significant data to interpret in the long and very long run between 2000 and 2005. The arrows all point left, indicating a negative relationship between the two variables. It appears that as time continues to move on, the 10Y3M will first trail the Dow Jones (increases/decreases in the stock market index precede like-movements in the 10Y3M). However, as time shifts to the very long run, the Dow Jones lags the Treasury spread.

Table 4.8: Time Period on Wavelet Graph and Date

Period	Date
0	2/1/1992
1000	10/28/1994
3000	4/19/2000
5000	10/10/2005
7000	4/2/2011

Conclusion

When is the next recession coming? Is it already here? How are people expected to navigate hardship if they don't know when it will arrive? While no answer can be definitive, especially in financial predictions, indicators like the Treasury yield curve inversion can set off warning signs that rougher times could be ahead. Outside of the industrial production analyses and the unemployment-10Y2Y, significant volatility is expected at various points in time across each variable (S&P 500, Dow Jones, and unemployment against the 10Y3M spread).

The SP500 DJD 10Y3M show middle and long-term volatility with the treasury likely to lead. Neither IP 10Y3M nor IP 10Y2Y has a strong correlation which makes sense because industrials are solid during recessionary times. The Unemployment 10Y3M shows significant long-term volatility, although the former displays no clear relationship with the 10Y2Y. Both daily data imply long-term volatility.

More importantly, the wavelets show that the yield curve inversion does in fact precede volatility in other economic factors. In one of the first wavelet analyses of recession prediction post-COVID, this paper maintains the statement that the Treasury yield curve inversion, specifically that of the 10-Year Minus 3-Month, is a strong indicator of financial recessions in the medium to long run. Given that inversions have occurred throughout 2022, only time can confirm the continued accuracy of the yield curve inversion.

Discussion

The largest limitation of this paper is that the oldest data point entry occurred in 1982. However, many more recessions and yield curve inversions have taken place before this. This model accounted for three recessions while an improved study could analyze five or six if data is retrieved that stretches back to the early 20th century. Additionally, this paper conducted a bivariate analysis while an alternate study could measure the impact of three or four variables at once.

Future studies should also incorporate a measure of the NASDAQ as well, which is one of the major broad, highly tech-centric stock market indices (technology companies have been the most volatile in the past two years). They would include an updated dataset with more available yield curve inversions and recessionary periods to identify. The most successful studies will accurately predict volatility in the Treasury curve to lead volatility in the S&P 500, Dow Jones, industrial production index, or unemployment.

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