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ANALYZING THE EFFECTIVENESS OF THE U.S. YIELD CURVE AS A LEADING ECONOMIC INDICATOR

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ABSTRACT

This thesis aims to contribute to the growing body of literature investigating the United States yield curve's predictive power of recessions. First, I discuss yield curve theory, explaining the structure of the yield curve and linking it to forward-looking interest rate expectations. I follow with a discussion of monetary policy, transmission lag, and potential pollutants of the yield curve's signal to establish the importance of the slope of the yield curve and to highlight the need for its evaluation as a reliable economic indicator. I then conduct a literature review covering the various techniques and approaches used in this field over the past few decades. Drawing from previous conclusions, I create a framework for study largely based on the probit model. I look at a full sample, a pre-1995 sample, and a post-1995 sample and analyze R^2 and log-likelihood values to assess the fits of various probit models. I conclude my analysis using vector autoregression (VAR) to measure the response between percent change in GDP and the slope of the yield curve.

From my analysis, I conclude that the yield curve still holds its standing as an effective forward-looking indicator, especially when used in conjunction with other explanatory variables in probit models. The yield curve is fundamentally tied to the market's expectations for future interest rates, which are determined by monetary policy. As long as central banks maintain credibility and markets continue to regard forward guidance, the yield curve should continue to be reliable.

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Chapter 1

Introduction

In a globalized world economy, it has become increasingly important for economic institutions to make effective monetary policy decisions. The consequences of policy missteps are no longer limited to individual countries or regions, but can destabilize the world's financial markets. Although many economic institutions enact monetary policy, the United States Federal Reserve System easily has one of the largest impacts along with a handful of central banks around the world.

One of the greatest challenges faced by the world's largest central banks stems from the presence of a lag in the effects of their policies. Monetary policy's effects on an economy are not seen immediately or uniformly around the world. Therefore, central banks must accurately predict future economic conditions before enacting the appropriate policy measures.

In this thesis, I will study the yield curve for United States Treasury securities ("Treasuries") and its use as a forward-looking macroeconomic indicator. The slope of the yield curve has been used by the Federal Reserve for decades, but its effectiveness has been questioned due to several factors I will discuss.

Several studies have been conducted since the 1990s regarding the status of the yield curve, and this growing body of knowledge will be summarized. I will use the probit model, a staple of existing literature, to conduct my analysis, and ultimately, I will attempt to determine whether the yield curve, with or without other explanatory variables, still has the same predictive power it has had in the past.

Chapter 2

Yield Curve Theory

The yield curve is a plot of yields of fixed income securities against time to maturity (Black et al., 2017). There is a wide range of yield curves, but I will specifically focus on the yield curve of U.S. Treasuries with maturities spanning from 3 months to 10 years. In stable economic conditions, the yield curve is usually upward sloping, indicating that longer maturities correspond with higher yields. In some cases, usually reflected by an impending recession, the yield curve flattens or even becomes downward sloping (Mishkin, 1990). This relationship between the slope of the yield curve and the state of the economy has made the yield curve a widespread macroeconomic indicator. In considering the yield curve's effectiveness, it is important to understand the three primary theories that affect interest rates: the expectations theory of the term structure of interest rates, the Fisher Effect, and the risk premium theory.

The expectations theory of the term structure of interest rates establishes the relationship between long term rates and expected short term rates, otherwise known as the term structure. It states that a long term interest rate is the average of the expected short term rates over the life of the long term security, which is shown in Equation 1 (Mishkin, 1990).

$$R_n = \frac{i_1 + i_{2e} + i_{3e} + \cdots + i_{ne}}{n} \qquad (1)$$

R_n is the interest rate of the long term security, i is the expected interest rate of a one year security at the time period indicated by its subscript, and n is the maturity of the long term security in years. For example, the interest rate on a 5 year U.S. Treasury is the average of the expected interest rates of five consecutively-held 1 year Treasuries. One key assumption of the expectations theory is that long term securities are perfect substitutes for consecutively-held short term securities (Mishkin, 1990). This means that there will be no difference in returns between investing in one 5 year Treasury and five consecutively-held 1 year Treasuries.

Equation 1 clearly shows the dependence of long term interest rates on market expectations of short term rates. If short term interest rates are expected to rise, long term interest rates will also rise. At the fundamental level, expectations of short term interest rates are tied to the Federal Reserve's use of the Federal Funds rate as a monetary policy tool. In poor economic conditions, the Federal Reserve reduces short term rates to encourage spending and borrowing. In improving economic conditions, the Federal Reserve increases interest rates to prevent the economy from expanding too rapidly (Vegh, 2001). By relating the slope of the yield curve to monetary policy expectations, the expectations theory effectively clarifies the importance of the yield curve as an economic indicator. The relationship between the yield curve and monetary policy can be further analyzed using the Fisher Effect to highlight the underlying role of inflation expectations.

The Fisher Effect relates real and nominal interest rates by stating that the real interest rate is equal to the nominal interest rate minus inflation (Black et al., 2017). This means that if inflation increases, the real interest rate, or the interest rate realized by consumers, will decrease given a constant nominal interest rate. Since one of the Federal Reserve's two policy mandates is stable prices, determined by the Federal Open Market Committee to be 2% inflation ("What are the Federal Reserve's objectives…," 2017), there is a clear link between inflation expectations and monetary policy. The reasoning behind raising interest rates to exercise contractionary monetary policy can also be interpreted using the Fisher Effect. A fast-growing economy with high consumption has the potential to induce inflation. In such a case, the Federal Reserve can raise nominal interest rates to combat expected inflation, thereby controlling the real interest rate.

The Fisher Effect and expectations theory can be combined to further solidify the yield curve's standing as a macroeconomic indicator. Inflation expectations affect monetary policy through the Fisher Effect, monetary policy affects short term interest rates, and short term interest rates affect long term interest rates through the expectations theory. This relationship between inflation and interest rates has also been proven quantitatively (Wallace & Warner, 1993).

Although short term interest rates and inflation expectations explain the positive slope of the yield curve in a stable economy, they do not fully capture the components that influence Treasury yields. Once again, the expectations theory is based on the key assumption that several short term securities and one long term security are perfect substitutes (Mishkin, 1990). In reality, this is not true, and the discrepancy can be partially explained by existence of a risk premium (Cochrane & Piazzesi, 2008).

The risk premium is a component of long term interest rates that captures the additional risk of holding a security for a longer period of time and is the difference between the interest rate derived from the expectations theory and the actual interest rate. The risk premium is sometimes broken into two components: the inflation risk premium and the liquidity risk premium. The inflation risk premium compensates investors for exposure to inflation risk, which would result in decreased purchasing power from the security's coupon payments due to high inflation. The liquidity premium compensates investors for potential liquidity risk, which may result in them not being able to sell a security in an illiquid market (Abrahams, Adrian, Crump, & Moench, 2016). Since risk increases with time, the risk premium is non-constant and is higher in longer-term securities than shorter ones.

Overall, interest rates of Treasury securities are defined as the sum of two components: the average of expected short term rates and the risk premium, with expected short term rates themselves being dependent on inflation expectations. These factors all influence the slope of the yield curve. When the economy is stable or growing, expectations of short term rates increase due to potential for inflation-controlling contractionary monetary policy, leading to higher yields on longer-term securities and an upward sloping yield curve. When the economy is contracting, expectations of short term rates fall due to expansionary monetary policy to increase borrowing and consumption, leading to lower long term rates than in a stable economy. Leading up to recessions, short term interest rate expectations are typically so low that long term securities have lower yields than short term securities, resulting in an inverted yield curve with a downward slope.

Chapter 3

Motivation of Study

The yield curve's forward-looking nature, resulting from theory basing it in economic expectations, makes it a unique and useful economic indicator. While other indicators such as percent change in GDP, stock market indices, inflation, and unemployment rate show the current state of the economy, the yield curve suggests future economic conditions, making it especially attractive in the realm of monetary policy.

History of Monetary Policy

Monetary policy and fiscal policy are the two tools used by governments to control economic activity. Monetary policy in the United States is conducted by the Federal Reserve, and it involves measures such as open market operations to control the money supply, controlling the Federal Funds rate, which is the interest rate banks pay to borrow from the Federal Reserve, and controlling the required reserve ratios of banks (Black, Hashimzade, & Myles, 2017). Fiscal policy is enacted by the government, and it involves modifications to government spending and taxation such as incentives in order to stimulate the economy (Black et al., 2017). Although monetary and fiscal policy have their own merits, the relative effectiveness of each has been debated since the 1960s (Kretzmer, 1992).

Since the 1970s, monetary policy has generally been considered the more effective of the two measures, initially due to the idea that inflation was related to money supply, which is a monetary issue. Governments around the world attempted to control inflation through the money supply, but these attempts failed when money supply targets were not met and money demand became unstable. This brought the shift to using interest rates to control inflation instead of meeting money supply targets. These ideas continued to prevail, and the role of monetary policy as the primary economic tool grew with the emergence of politically independent central banks in the 1990s. It was decided that central banks should be primarily responsible for managing the economy through monetary policy instead of politicians, who may be prone to making short term decisions based on reelection campaigns (Arestis & Sawyer, 2004).

This change firmly established the central bank as the key figure in controlling the economy and managing inflation expectations. Worldwide, fiscal policy was no longer treated as the primary option to make minor adjustments to the economy. Instead, fiscal policy is now considered to be a relatively constant factor when compared to monetary policy, and previous fiscal policy targets of high employment are now achieved through labor law changes and labor market regulations (Arestis & Sawyer, 2004). The Federal Reserve's policy mandates are stable prices, or roughly 2% yearly inflation, and full employment, defined by a roughly 5% unemployment rate ("What are the Federal Reserve's objectives…," 2017). As discussed previously, inflation expectations are a key component in determining long term rates, and the Federal Reserve has since cemented itself as the authority for inflation targets by communicating its economic expectations and by consistently achieving its inflation target (Arestis & Sawyer, 2004).

Establishing credibility by relaying inflation and economic expectations is highly important for the Federal Reserve as the economic authority and central bank of the United States. In particular, the Federal Reserve needs a reliable forward-looking economic indicator to assess market expectations as well as the effectiveness of its monetary policy. Further amplifying the need for a reliable forward-looking indicator is the presence of a monetary policy lag, which has been theorized and observed for decades.

Monetary Policy Lag

The monetary policy lag is the amount of time taken for monetary policy to have its peak desired effect on the economy, whether through inflation or output. Monetary policy lag, also called transmission lag, can be derived from five main sources. The first source is the delay seen in the pass through of the central bank's adjustment of a baseline rate to deposit and lending rates set by financial institutions. The second source of lag is the response time of businesses and consumers to changes in monetary policy. This lag specifically pertains to the simple decision of whether to invest presently or to postpone investment in favor of different economic conditions. The third source is the time taken for the asset markets to take into account monetary policy in pricing. The fourth source is the delay in the reaction of exchange rates to monetary policy, which is important to trade-related sectors of the economy. Finally, the transmission of monetary policy effects from directly affected sectors of the economy outward into other parts of the economy takes time (Gruen, Romalis, & Chandra, 1999).

The monetary policy lag was first estimated in 1961, a time when money supply control was a key fixture of monetary policy, to be a 20 month lag for money supply M1 and a 23 month lag for money supply M2 (Friedman, 1961). Over time, this lag has been analyzed and found to hold true in the United States. Friedman's lag estimate has stood to be so accurate that the lag between monetary policy implementation and intended effect on inflation has commonly been estimated worldwide to be 2 years. During the 1980s, it was debated whether innovations in the financial markets and information processing along with the high-inflation period of the 1970s had changed how monetary policy was transmitted throughout the economy. Although asset prices in particular reacted more quickly to monetary policy, transmission lag had not shortened significantly, supported by studies of U.S., U.K., and Australian financial markets (Batini & Nelson, 2001; Gruen et al., 1999).

Literature written worldwide since 2000 before and after the 2008 global financial crisis has supported the existence of long and variable monetary policy lags. Lags have not shortened as was thought in the decades prior, but in general, they seem to have remained stable. According to Havranek & Rusnak (2013), financial development corresponds to a lengthened transmission lag. In a less-developed financial system, financial institutions have fewer tools to prepare for and protect themselves against unexpected monetary policy. This forces these institutions to respond quickly, leading to a decreased policy lag. Contrarily, highly developed financial systems have many tools and resources to analyze monetary policy actions, leading to hedges and a generally slower transmission. Despite these findings, the monetary policy lag is estimated to be 2 years worldwide (Havranek & Rusnak, 2013).

Overall, monetary policy lag is a phenomenon that has been observed and will continue to be observed. The presence of this lag further establishes the need of a reliable forward-looking economic indicator for central banks like the Federal Reserve. In the past, this need has been filled by the yield curve, but there has been discussion about its potentially diminishing effectiveness.

Potential Pollutants of the Yield Curve

Since 1960, the yield curve has taken an inverted shape prior to every recession, indicating its accuracy as a forward-looking indicator (Estrella & Trubin, 2006). Since the late 1990s however, the yield curve’s predictive power has been questioned due to the increased number of pollutants that have the potential to disrupt its signal. One major pollutant has been the globalization of financial markets, especially in light of the 2008 recession. Prior to rapid globalization at the end of the 20th century, it was relatively uncommon to hold assets of other countries, including U.S. Treasury securities. Now, U.S. Treasuries are easily accessible, and many foreign governments and central banks retain significant holdings (Bernanke, 2013). This accessibility also feeds into the widely held perception of U.S. Treasuries as a safe haven asset. When economic conditions are poor, foreign demand of U.S. Treasuries can increase prices and thereby artificially reduce yields without altering the expected path of short term real interest rates or inflation expectations. The low-rate environment following the financial crisis has further exacerbated this phenomenon, with foreign investors turning to U.S. Treasuries for higher yields as the Federal Reserve continues to raise the Federal Funds rate at a faster pace than many other central banks (Bernanke, 2013).

Another effect of the Federal Reserve's monetary policy operations during the financial crisis is the artificial lowering of the term premium, or risk premium. In traditional theory explaining the shape of the yield curve, the term premium is constant. During the financial crisis, the Federal Reserve engaged in large-scale asset purchasing programs called quantitative easing, which effectively lowered the term premium on long term securities by decreasing their supply. This artificial lowering of long term rates reduced the slope of the yield curve, potentially polluting its signal.

Both of these effects related to globalization of financial markets can also be tied to the global savings glut (GSG), a hypothesis first proposed by Ben Bernanke in 2005. The hypothesis explains the unusual American economic conditions that prevailed pre-recession, when interest rates on U.S. Treasuries as well as loans and mortgages were surprisingly low. The GSG hypothesis revolves around trade imbalances in the form of current account surpluses in emerging markets such as Asia and current account deficits in developed countries like the

United States. These trade imbalances had left the United States in an unusual position as a net borrower on international capital markets, and they had made many emerging market economies into net lenders (Bernanke, 2005).

According to the GSG hypothesis, these unusual trade balances were caused by a shift toward saving by developing countries in Asia as well as oil exporters. This increase in savings can be explained by several factors. First, Asian financial crises of the late 1990s led to decreased confidence in the financial institutions of those countries, which led to decreased investment. These events also led to policy changes which notably included the accumulation of foreign currency reserves, including U.S. dollars. In the case of Middle Eastern oil exporters, higher crude oil prices increased incomes more than consumption, leading to increased savings. Lastly, Chinese household savings increased due to income growth and a lack of confidence in the country's social safety net (Bernanke, 2007). Increased savings in emerging markets led to investment in safe haven U.S. Treasuries, increasing their prices and thus reducing their yields. It is believed that these reduced rates, especially on mortgages, contributed to the housing bubble in the United States. These reductions in yields were further reinforced by shifts in European investor preferences to U.S. fixed income assets, including Treasuries. Although developed European nations did not run current account surpluses, they issued large amounts of bank and sovereign debt, and the proceedings from these sales were used to purchase U.S. securities (Bernanke, Bertaut, DeMarco, & Kamin, 2011).

The global savings glut is expected to increase further, having the potential to sustain downward pressure on U.S. yields, which would affect the slope of the yield curve. One of the most important reasons for increased future savings in industrial economies is the demographic shift to older populations (Poole, 2007). As the ratio of retirees to workers increases in countries worldwide, government saving can also be expected to increase, leading to depressed yields in U.S. Treasury markets (Bernanke et al., 2011).

In theory, the yield curve can provide a wealth of economic information including market sentiment and inflation expectations, and it has been very effective in previous recessions. However, in the post-recession era of globalization of financial markets, artificial manipulation of interest rates by central banks, and an increase in global savings, the yield curve’s validity as a reliable forward-looking economic indicator should be reevaluated.

Chapter 4

Literature Review

Several studies over the past few decades have attempted to quantify the effectiveness of the United States yield curve on predicting future recessions. Although economic conditions have varied dramatically over time, the basic premise of these studies has remained largely the same - develop a quantitative model that uses the yield curve to output the probability of recession and assess its accuracy in past recessions. Most of these studies utilize the probit model, and I will discuss these chronologically.

The first study to inspect the slope of the yield curve as a predictor of future economic activity was conducted by Estrella and Hardouvelis (1991). Prior to this, interpretation of the slope of the yield curve had been limited to predicting future interest rates. For example, the flattening of the yield curve in the late 1980s was seen as a sign of lower future rates, which were treated as a proxy for lower future output. However, a direct link between the slope of the yield curve and economic output had not been established. Estrella and Hardouvelis sought to find such a link by determining whether the term structure of interest rates carried information not available in other macroeconomic indicators. Their initial model held the cumulative percent change in real Gross National Product (GNP) as a function of the spread between the 10 year and 3 month Treasuries. The model’s in-sample results confirmed that the slope of the yield curve could be used to predict cumulative GNP changes up to 4 years ahead and marginal GNP changes up to 6 or 7 quarters ahead. For a forecasting horizon of four to seven quarters, the slope of the yield curve accounted for over 33% of variation in cumulative change in GNP. This model established the first direct quantitative link between the slope of the yield curve and economic output. Estrella and Hardouvelis also built a probit model where the probability of recession, ranging from 0 to 1, was a function of the rate spread term lagged by 4 quarters. The result was a model with a pseudo-R^2 value, which determined the overall fit of the model, of 0.297. The probit model's coefficients showed a statistically significant relationship between the probability of recession and the lagged slope of the yield curve, but the model's non-linear nature made it difficult to draw a definite quantitative conclusion. Instead, the model's probabilities of recession were graphically compared to actual recessions from 1956 through 1988 as per the National Bureau of Economic Research. The resulting plot showed that the probit model's peaks corresponded to actual recessions except in the case of 1966-1967, where a 40% probability of recession corresponded to an economic slowdown, not a recession. However, the model only yielded probabilities of recession of over 70% for three of the six recessions shown, suggesting that it was not a strong indicator of recessions. Overall, the importance of this study was in the establishment of a relationship between the slope of the yield curve and change in economic output and the first generation of a probit model using the slope of the yield curve as an explanatory variable (Estrella & Hardouvelis, 1991).

This probit model methodology to analyze the effectiveness of indicators in predicting recessions was used again by Estrella and Mishkin (1996). Probit models were used to determine which indicators were the most effective in predicting recessions one to six quarters into the future. The variables studied included the New York Stock Exchange stock price index, the Commerce Department's index of leading economic indicators, the Stock-Watson index of leading indicators, and the slope of the yield curve between the 10 year and 3 month Treasuries. Each variable proved to have some accuracy in forecasting out-of-sample recessions, but the results were broken down into two time-dependent regions. In forecasting recession probabilities one quarter ahead, the Stock-Watson index produced the best results, and in predicting recessions two or more quarters ahead, the yield curve definitively produced the strongest results. Furthermore, the relative strength of the yield curve's predictive power increased as the forecast horizon increased, though it was most effective in predicting recessions four quarters ahead. This study established the practice of using probit models to generate recession forecasts. It also established the legitimacy of the yield curve as a forward-looking indicator at a forecast horizon of four quarters (Estrella & Mishkin, 1996).

Michael Dueker (1997) conducted another probit model study based on the results of Estrella, Mishkin, and others. Similarly, Dueker generated probit models to test the accuracies of the slope of the yield curve, the index of leading indicators, real M2 growth, the percentage spread between 6 month commercial paper and the 6 month Treasury bill, and the percentage change in the S&P 500 on predicting recessions. He tested forecast horizons ranging from three to twelve months and also compared results from models with non-lagged and 3-month lagged independent variables. Using pseudo-R^2 and log-likelihood values to evaluate the effectiveness of each model, Dueker concluded that for forecast horizons greater than 3 months, the yield curve was the most effective recession predictor, and its effectiveness peaked at a forecast horizon of 9 months. In comparing non-lagged and lagged independent variables, Dueker found that non-lagged models failed to absolutely predict the onset or duration of recessions while 3-month lagged models could better calculate duration but could still not determine onset. Overall, this study confirmed Estrella and Mishkin's findings and also proved that models with lagged explanatory variables were more effective in predicting recessions (Dueker, 1997).

Jonathan Wright (2006) conducted a study that tested several variations on the probit model that had been used in the past. Most notably, this study was the first to include other independent variables besides the slope of the yield curve in generating multivariate probit models. The first model was a basic probit model that featured the non-lagged yield curve spread as the only independent variable. The second model added the nominal Federal Funds rate as a second independent variable, while the third model added both the nominal and real Federal Funds rates to the yield curve spread. The first model delivered the expected result of a highly statistically significant coefficient on the yield curve term at the two, four, and six quarter forecast horizons. In the second model, the coefficients on the yield curve term and the nominal Federal Funds rate were significant at all forecast horizons. In the third model, the coefficients on the yield curve and nominal Federal Funds rate were statistically significant while the coefficient on the real Federal Funds rate was not significant. Overall, the fit of each model was judged according to its McFadden R^2 value and Bayes information criterion. For all horizons, both models that included some form of the federal funds rate had higher McFadden R^2 values than the baseline model with only the yield curve spread. It should be noted that McFadden R^2 values were highest for the four quarter forecast horizon. Judging from the Bayes information criterion, the second model featuring the yield curve spread and nominal federal funds rate fit the sample best at all horizons. Wright also tested the second model's out-of-sample predictive performance using root mean square errors of predictions and concluded that it was not over fitted (Wright, 2006).

The next major advancement in the study of the yield curve as a forward-looking indicator was the use of dynamic binary response models, which were first proposed by Kauppi and Saikkonen (2008). Up to this point, the probit models, which are binary response models, were static, meaning that they did not take into account the current state of the economy through the current value of the binary variable in predicting a future recession. In these models, the independent variables were lagged or non-lagged yield curve slopes and the Federal Funds rate.

In the dynamic binary response models, a lagged version of the binary response was added as an explanatory variable, allowing for the inclusion of the current state of the economy. These dynamic models consistently performed better than the static models in both in-sample and out-of-sample trials. Dynamic models that contained a lagged version of the binary response variable also performed better than those which used a lagged version of the probit probability variable (Kauppi & Saikkonen, 2008).

Dynamic probit models were further studied by Henri Nyberg (2010). Nyberg created dynamic models using financial indicators from the United States and Germany and analyzed how effective they were in forecasting the 2008 recession in their respective countries. The in-sample and out-of-sample results for the United States and Germany showed that the dynamic models were the best predictors, confirming the results of Kauppi and Saikkonen. Nyberg's dynamic models also used other dependent variables like lagged stock returns and the foreign term spread, which added to the model's predictive power (Nyberg, 2010).

The most recent study on the topic of recession predictability using the yield curve was conducted by Liu and Moench (2016). They used univariate and multivariate probit models to test in-sample and out-of-sample predictability of recessions. However, instead of using an R^2 value to assess the strength of the models, they used the receiver operating characteristic (ROC) curve. This measure will not be utilized in this thesis for the sake of consistency in evaluation with most other studies. For each forecast horizon studied, the baseline probit model only had the yield curve spread as the dependent variable. Then, a second baseline model was created with the yield curve spread and the spread lagged by six months. Finally, other models were created by adding one financial or economic indicator to the two initial explanatory variables based on the yield curve. Although five forecast horizons were studied, the effectiveness of each baseline model in in-sample and out-of-sample tests peaked at a forecast horizon of 12 months, which was consistent with many previous studies. At this horizon in the in-sample study, the 10 year Treasury - Federal Funds rate spread, 1 year Treasury - Federal Funds rate spread, and 5 year Treasury - Federal Funds rate spread were the three most effective additional explanatory variables. At forecast horizons shorter than 12 months, the S&P 500's one year percentage return improved the effectiveness of the two yield curve terms. For all horizons, the addition of the lagged yield curve term improved the strength of prediction. In the out-of-sample test, adding the lagged yield curve spread also helped for all horizons. At the 12 month horizon, the variables that helped the most were the National Association of Purchasing Managers (NAPM) consumer commodity price index, NAPM vendor deliveries, and the Federal Funds rate. Overall, this study concluded that the ability of the slope of the yield curve to predict recessions was strongest at a 12 month forecast horizon and showed that the addition of a lagged spread term improved effectiveness (Liu & Moench, 2016).

The use of the slope of the yield curve to predict recessions has been studied for many years, and it has been approached from a variety of angles. I created the methodology for this thesis by taking into account the conclusions of previous studies and by employing the alternative analysis method of vector autoregression (VAR).

Chapter 5

Methodology

The methods used in this study were drawn from previous studies and are largely based upon the evaluation of a probit model for its accuracy in predicting recessions in in-sample tests for a full sample and smaller samples split based on economic climate. Static and dynamic probit models were also tested, with dynamic models containing a lagged binary variable to take the current state of the economy into account. Vector autoregression (VAR) was also used to assess the relationship between the slope of the yield curve and the quarter-over-quarter percent change in GDP.

Using quarterly data, a binary variable, *rec*, was assigned a value of 0 or 1 depending on whether there was a recession or not according to the National Bureau of Economic Research's definition. A recession was defined as the time period from the peak of a business cycle to its trough ("US Business Cycle Expansions and Contrations," n.d.). This binary variable was created manually and used as the dependent variable for all probit models. The generic equation for a probit model with one lagged explanatory variable is shown in Equation 2 (Dueker, 1997) where Φ is the cumulative standard normal density function, c_0 is a constant for the error, c_1 is the exogenous variable's coefficient, X is the explanatory variable, t is the current time period, and k is the lag in quarters on the explanatory variable. All probit models followed this form, with additional explanatory variables being added as necessary. I also used a forecast horizon of 4 quarters for all models (k = 4), consistent with the findings of Liu and Moench (2016).

$$Prob(rec = 1) = \Phi(c_0 + c_1 X_{t-k}) \qquad (2)$$

Most of the data used in this study was collected from Federal Reserve Economic Data (FRED) from the Federal Reserve Bank of St. Louis ("FRED Economic Data," n.d.). Only price change data for the S&P 500 index was obtained from the Bloomberg Terminal ("Bloomberg Professional Service," n.d.). All variables and their abbreviations are shown in Table 1.

Definition	Abbreviation
Recession Binary Variable	rec
Slope of the Yield Curve (10 yr Treasury - 3 month Treasury)	syc
1 year S&P 500 % change in price	sp1yr
3 year S&P 500 % change in price	sp3yr
Housing Starts YoY % change	house
Industrial Production QoQ % change	indpro
Unemployment Rate (%)	unemp
1 yr Treasury - Federal Funds Rate spread (%)	gs1_ff
5 yr Treasury - Federal Funds Rate spread (%)	gs5_ff
10 yr Treasury - Federal Funds Rate spread (%)	gs10_ff
Moody's Aaa Corporate - 10 yr Treasury spread (%)	aaa_gs10
Moody's Baa Corporate - 10 yr Treasury spread (%)	baa_gs10

Table 1. Variable descriptions and abbreviations

McFadden R^2 and log-likelihood values were used to determine the effectiveness of each probit model. I chose these two metrics because they are the predominant evaluation measures used in previous studies. The formula for McFadden R^2 is shown in Equation 3 where L_0 is the likelihood for a model without predictors and L_M is the likelihood for the model being estimated (Veall & Zimmerman, 1996). The formula for log-likelihood, L, is shown in Equation 4 (Dueker, 1997).

$$R^2{}_{McF} = 1 - \frac{\ln L_M}{\ln L_0} \qquad (3)$$

$$L = \sum_t rec \times \ln Prob(rec = 1|X_{t-k}) + (1 - rec) \times \ln Prob(rec = 0|X_{t-k}) \qquad (4)$$

I began my analysis by generating a number of in-sample probit models for the full sample 1964Q1 to 2017Q4, following the start date used by several researchers to ensure reliable data on long term Treasuries (Wright, 2006). The first three baseline models that only used the yield curve slope or lagged binary variable are summarized in Table 3. Here, I aimed to test one of Liu and Moench's (2016) findings that adding an additional yield curve term lagged 6 quarters was beneficial.

Explanatory Variables (lag in quarters)	Model Type
YC slope$_{t-4}$	Static
YC slope$_{t-4}$ + YC slope$_{t-6}$	Static
YC slope$_{t-4}$ + YC slope$_{t-6}$ + rec$_{t-4}$	Dynamic

Table 2. Baseline Probit Models

Next, I tested several models using combinations of the exogenous variables listed in Table 1, the slope of the yield curve, and the binary recession variable. These models, which I will call 'diverse', are summarized in Table 4, and 'var' is used as a placeholder for the additional explanatory variable in the model.

Explanatory Variables (lag in quarters)	Model Type
var$_{t-4}$	Static
YC slope$_{t-4}$ + YC slope$_{t-6}$ + var$_{t-4}$	Static
YC slope$_{t-4}$ + YC slope$_{t-6}$ + var$_{t-4}$ + rec$_{t-4}$	Dynamic

Table 3. Diverse Probit Models

The split sample analysis was carried out in the same manner. The first sample was 1964Q1 to 1994Q4, and the second sample was 1995Q1 to 2017Q4. This point was chosen because I believed it is around the time when financial markets began rapid globalization with the rise of technology. This break also followed the period of high inflation of the 1980s. The same models described in Tables 2 and 3 were tested for both split samples.

Finally, I used VAR to measure the response between the percent change in GDP and the slope of the yield curve. Essentially, the VAR allowed me to quantitatively capture the dependencies between the time series of change in GDP and yield curve.

Chapter 6

Results and Discussion

Full Sample

The McFadden R^2 and log-likelihood results for the baseline models described in Table 2 are shown in Table 4.

Explanatory Variables (lag in quarters)	McFadden R^2	Log-Likelihood
YC slope$_{t-4}$	0.269	-68.4
YC slope$_{t-4}$ + YC slope$_{t-6}$	0.327	-63.3
YC slope$_{t-4}$ + YC slope$_{t-6}$ + rec$_{t-4}$	0.328	-63.2

Table 4. Full Sample Baseline Results

The results from the full sample test were most useful in providing a standard of comparison and in confirming that adding a yield curve term that was lagged 6 quarters improved the model, as shown by the increased McFadden R^2 and the reduced magnitude in the log-likelihood. This improvement also highlights one of the key aspects of the study of the yield curve in this thesis - the ultimate goal is to develop a model that is accurate in predicting recessions in order to show the yield curve's effectiveness. This differs from traditional economic models in that the explanatory variables can be dependent on one another or redundant, but this has been deemed acceptable in previous studies given the objective. Adding the binary variable *rec* did not improve the model much in the full-sample test, which will be a point to remember when looking at both split sample tests. McFadden R^2 results for the diverse probit models are shown in Table 5, and the log-likelihood results are shown in Table 6.

Variable (var)	var_{t-4}	YC $slope_{t-4}$ + YC $slope_{t-6}$ + var_{t-4}	YC $slope_{t-4}$ + YC $slope_{t-6}$ + var_{t-4} + rec_{t-4}
sp1yr	0.002	0.335	0.342
sp3yr	0.006	0.330	0.332
house	0.119	0.342	0.343
indpro	0.003	0.327	0.328
unemp	0.077	0.328	0.329
gs1_ff	0.188	0.338	0.339
gs5_ff	0.289	**0.343**	**0.344**
gs10_ff	**0.299**	0.341	0.342
aaa_gs10	0.046	0.330	0.330
baa_gs10	0.019	0.340	0.341

Table 5. Full Sample Diverse McFadden R^2

Variable (var)	var_{t-4}	YC $slope_{t-4}$ + YC $slope_{t-6}$ + var_{t-4}	YC $slope_{t-4}$ + YC $slope_{t-6}$ + var_{t-4} + rec_{t-4}
sp1yr	-93.8	-62.5	-61.9
sp3yr	-93.5	-63.0	-62.8
house	-82.9	-61.9	-61.8
indpro	-93.8	-63.3	-63.2
unemp	-86.8	-63.2	-63.1
gs1_ff	-76.3	-62.2	-62.2
gs5_ff	-66.9	**-61.8**	**-61.7**
gs10_ff	**-65.9**	-61.9	-61.8
aaa_gs10	-89.7	-63.0	-63.0
baa_gs10	-92.2	-62.0	-61.9

Table 6. Full Sample Diverse Log-Likelihood

It is also worth noting that three explanatory variables, *gs1_ff, gs5_ff, and gs10_ff* are themselves different yield curve slopes. When comparing the results from the variable-only models using these variables to variable-only models with the other ones, it is easy to see their higher McFadden R^2 values, indicating that yield curve slopes were on their own better fitting than other variables. The full sample results also indicate that since 1964, the spread between the 5 year Treasury and the Federal Funds rate has been the best explanatory variable to add to the two yield curve slope terms, yielding a McFadden R^2 of 0.343 and a log-likelihood of -61.8. These findings reaffirms that interest rate spreads are better at predicting economic output than other indicators. Second, the advantage of the 5 year Treasury - Federal Funds rate spread over the 10 year Treasury - Federal Funds rate spread ties back to the expectations theory of the term structure of interest rate. The 10 year rate takes into account the interest rates of 1 year Treasuries up to 10 years in the future, while the 5 year rate only uses future 1 year rates up to 5 years in the future. The preference of the 5 year rate suggests that markets view forward guidance to be more effective 5 years into the future than 10 years. This is logical, and it may also suggest that intermediate-maturity Treasuries are the best explanatory variables to consider in these probit models.

The full sample results also show that dynamic models which include a lagged *rec* term as an explanatory variable are not significantly better predictors than the static models. Similar to the baseline findings, this result should be remembered when considering split sample dynamic models.

Pre-1995 Split Sample

The first split sample ranged from 1964Q1 to 1994Q4, which I believed would provide an appropriate insight into the effectiveness of the yield curve before the rapid globalization of financial markets. This time period also included several important recessions and the inflationary period of the 1980s. The McFadden R^2 and log-likelihood results for the baseline models described in Table 2 are shown in Table 7.

Explanatory Variables (lag in quarters)	McFadden R^2	Log-Likelihood
YC slope$_{t-4}$	0.264	-43.8
YC slope$_{t-4}$ + YC slope$_{t-6}$	0.310	-41.1
YC slope$_{t-4}$ + YC slope$_{t-6}$ + rec$_{t-4}$	0.313	-40.8

Table 7. Pre-1995 Baseline Results

Similar to the full sample results, the pre-1995 baseline results confirm that adding a yield curve slope lagged 6 quarters improves the model’s fit. However, each model had a worse fit to the data than the baseline models constructed in the full sample test in Table 4. This suggests that the yield curve generally was not as effective prior to 1995 when compared to the overall sample. The addition of the binary variable *rec* again only had a minor impact on the fit of the two yield curve terms. McFadden R^2 results for the diverse pre-1995 probit models are shown in Table 8, and the log-likelihood results are shown in Table 9.

Variable (var)	var_{t-4}	YC $slope_{t-4}$ + YC $slope_{t-6}$ + var_{t-4}	YC $slope_{t-4}$ + YC $slope_{t-6}$ + var_{t-4} + rec_{t-4}
sp1yr	0.002	0.337	0.337
sp3yr	0.001	**0.338**	**0.339**
house	0.075	0.310	0.313
indpro	0.003	0.311	0.314
unemp	0.047	0.310	0.317
gs1_ff	0.185	0.318	0.328
gs5_ff	0.278	0.324	0.337
gs10_ff	**0.291**	0.326	0.343
aaa_gs10	0.080	0.312	0.314
baa_gs10	0.016	0.315	0.327

Table 8. Pre-1995 Diverse McFadden R^2

Variable (var)	var_{t-4}	YC $slope_{t-4}$ + YC $slope_{t-6}$ + var_{t-4}	YC $slope_{t-4}$ + YC $slope_{t-6}$ + var_{t-4} + rec_{t-4}
sp1yr	-59.3	-39.4	-39.4
sp3yr	-59.4	**-39.3**	-39.3
house	-55.0	-41.0	-40.8
indpro	-59.3	-41.0	-40.8
unemp	-56.7	-41.0	-40.6
gs1_ff	-48.5	-40.6	-40.0
gs5_ff	-43.0	-40.2	-39.4
gs10_ff	**-42.2**	-40.1	**-39.1**
aaa_gs10	-54.7	-40.9	-40.8
baa_gs10	-58.5	-40.7	-40.0

Table 9. Pre-1995 Diverse Log-Likelihood

For the pre-1995 results, I primarily considered McFadden R^2 results as opposed to log-likelihood to determine the effectiveness of a model to maintain consistency in results. Accordingly, I found that the 3 year price change of the S&P 500 index was the best explanatory variable to add to the yield curve terms, yielding an R^2 value of 0.338 and a log-likelihood of -39.3. Since the S&P 500's price change is not directly tied to interest rates, this result contrasts that of the full sample, where the 5 year Treasury - Federal Funds spread was the best explanatory variable. This disparity suggests that interest rates may not have been as important as U.S. stock market returns when predicting future economic conditions prior to 1995. This may be explained by the many changes that occurred in monetary policy techniques before 1995. Prior to the 1990s, techniques of monetary policy were still not firm, so it is reasonable to suggest that the financial markets looked to equity indices instead of interest rates to gauge future economic growth. Furthermore, the Federal Reserve's forward guidance may not have been regarded as highly as in the post-1995 period.

Overall, the dynamic models containing the lagged binary variable *rec* performed noticeably better than the static models, which was not the case in the full sample tests. Static models with already-high McFadden R^2 values did not see a large change with the addition of lagged *rec*, but there were notable improvements in models where the explanatory variable was a spread between a Treasury and the Federal Funds rate.

Post-1995 Split Sample

The second part of the split sample ran from 1995Q1 to 2017Q4, which I chose to parallel increased globalization through technology as well as the two most recent recessions in the 2000s. I particularly wanted to observe the effect the 2008 financial crisis would have on the models, considering that economic institutions' responses were very different from those in previous recessions due to quantitative easing. The McFadden R^2 and log-likelihood results for the baseline models described in Table 2 are shown in Table 10.

Explanatory Variables (lag in quarters)	McFadden R^2	Log-Likelihood
YC slope$_{t-4}$	0.266	-24.7
YC slope$_{t-4}$ + YC slope$_{t-6}$	0.379	-20.9
YC slope$_{t-4}$ + YC slope$_{t-6}$ + rec$_{t-4}$	0.432	-19.1

Table 10. Post-1995 Baseline Results

The post-1995 results show the most drastic improvements in McFadden R^2 with the additions of an additional yield curve term and *rec* for the dynamic model. This firmly confirms Liu and Moench's (2016) conclusion that adding a yield curve term lagged 6 quarters is beneficial to fit. It also suggests that the presence of an additional yield curve term has become even more important since 1995. The impact of the addition of the binary variable *rec* was considerable in the post-1995 sample, indicating that the current state of the economy may be more important to predicting economic conditions than it has been in the past. McFadden R^2 results for the diverse post-1995 probit models are shown in Table 11, and the log-likelihood results are shown in Table 12.

Variable (var)	var$_{t-4}$	YC slope$_{t-4}$ + YC slope$_{t-6}$ + var$_{t-4}$	YC slope$_{t-4}$ + YC slope$_{t-6}$ + var$_{t-4}$ + rec$_{t-4}$
sp1yr	0.003	0.384	0.437
sp3yr	0.033	0.389	0.432
house	0.255	**0.604**	**0.604**
indpro	0.009	0.398	0.432
unemp	0.293	0.391	0.445
gs1_ff	0.276	0.410	0.438
gs5_ff	**0.378**	0.427	0.451
gs10_ff	0.364	0.445	0.468
aaa_gs10	0.011	0.389	0.432
baa_gs10	0.006	0.412	0.435

Table 11. Post-1995 Diverse McFadden R^2

Variable (var)	var$_{t-4}$	YC slope$_{t-4}$ + YC slope$_{t-6}$ + var$_{t-4}$	YC slope$_{t-4}$ + YC slope$_{t-6}$ + var$_{t-4}$ + rec$_{t-4}$
sp1yr	-33.6	-20.7	-19.0
sp3yr	-32.6	-20.6	-19.1
house	-25.1	**-13.3**	**-13.3**
indpro	-33.4	-20.3	-19.1
unemp	-23.8	-20.5	-18.7
gs1_ff	-24.4	-19.9	-18.9
gs5_ff	**-21.0**	-19.3	-18.5
gs10_ff	-21.4	-18.7	-17.9
aaa_gs10	-33.3	-20.6	-19.1
baa_gs10	-33.5	-19.8	-19.0

Table 12. Post-1995 Diverse Log-Likelihood

The post-1995 results are unsurprisingly dominated by models that contain year-over-year percent change in housing starts as the explanatory variable in addition to the yield curve terms, resulting in a McFadden R^2 of 0.604 and a log-likelihood of -13.3. Aside from housing starts, the explanatory variable that provides the best fit is the 10 year Treasury - Federal Funds rate spread, closely followed by the 5 year and 1 year Treasury spreads with the Federal Funds rate. The high R^2 values for models with these explanatory variables suggests that markets have regarded Treasury spreads with the Federal Funds rate as reliable economic predictors since 1995. Although these spreads are also slopes of yield curves, they are not the traditional slope, which is defined as the spread between the 10 year and 3 month Treasuries. The use of these alternate spreads with the Federal Funds rate as opposed to the 3 month Treasury may be an attempt of the market to improve stability. The Federal Funds rate fluctuates far less than the 3 month Treasury rate and therefore is not prone to spikes caused by short term events, which may make it attractive to investors seeking a stable indicator.

Another important result of the post-1995 sample is that the resulting R^2 values for all models are significantly higher than the R^2 values for the corresponding models in the pre-1995 sample. This suggests that since 1995, probit models in general have been more effective in fitting the recession binary variable. This could be due to predicted globalization in the form of increased access to information caused by technology and financial innovation. As markets around the world have increased access to global financial information, investors are more likely to base their decisions on macroeconomic variables, including the yield curve, than they were before.

Finally, the dynamic models with the binary response variable *rec* performed similarly to the corresponding dynamic models in the pre-1995 sample. The addition of *rec* to static models improved the fit of some models noticeably, but did not improve already well-fitted models as much. Again, this may indicate that including the current state of the economy through a lagged *rec* term generally improves the fit of probit models.

VAR Analysis

The final analysis that I conducted was vector autoregression, which measured the response between the quarterly percent change in GDP (pcgdp) and the slope of the yield curve (syc). In Figures 1 and 2, the x axis represents the lag in quarters and the solid blue line indicates the response of the dependent variable in percent as a function of time from the one unit impulse in the x variable.

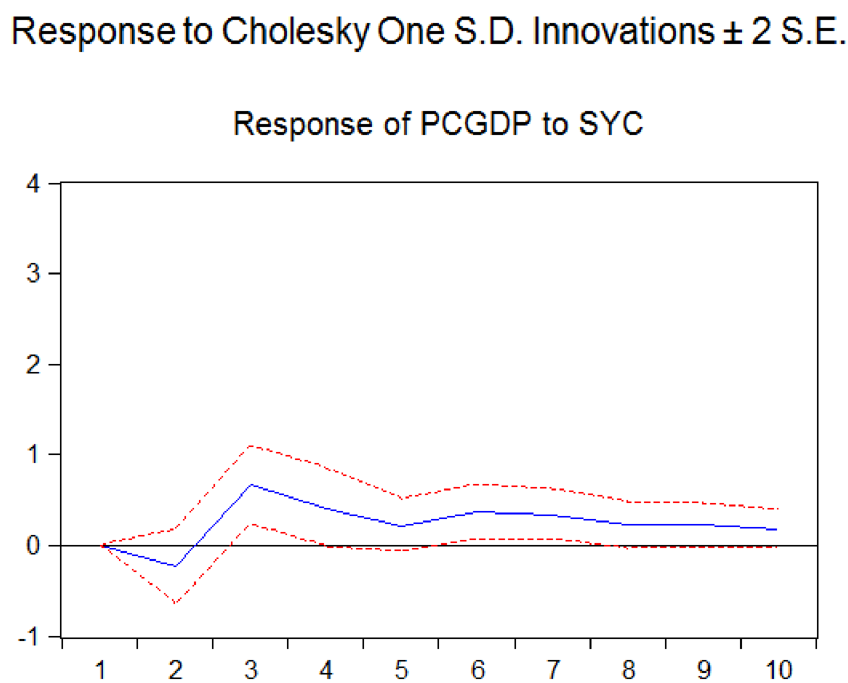

Figure 1. Response of quarterly percent change in GDP to yield curve slope

Figure 1 shows the effective monetary policy lag incurred. There is a spike in the third quarter after the impulse, indicating that 3 quarters after an impulse to the slope of the yield curve of 1%, the quarterly percent change in GDP will increase by roughly 0.7%. The initial impulse to increase the yield curve slope can be likened to the Federal Reserve lowering the Federal Funds rate to stimulate economic growth through expansionary policy. This change would deliver a positive impact on the economy that would begin to be felt at approximately 3 quarters after the policy decision. This interpretation is consistent with the expected monetary policy lag discussed previously.

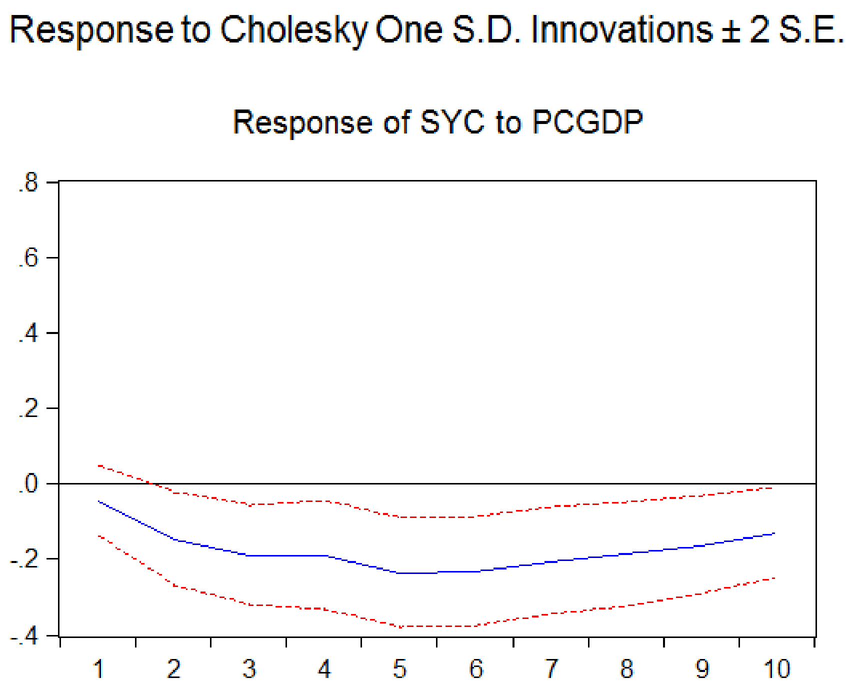

Figure 2. Response of yield curve slope to quarterly percent change in GDP

Figure 2 shows the market's reaction to a positive change in GDP, which eventually influences the slope of the yield curve. The response steadily decreases after the impulse and reaches its minimum in the 5th quarter. This indicates that a 1% increase in the quarterly percent change in GDP will deliver a maximum reduction in the slope of the yield curve of roughly 0.2% after 5 quarters. A decrease in the yield curve's slope can be seen as the market's expectation that the Federal Reserve will exercise contractionary monetary policy by raising the Federal Funds rate, and this action will occur 5 quarters into the future. Although I did not discuss the possible reverse causality between the slope of the yield curve and GDP change extensively in this thesis, it is important to realize that the two are very interdependent. This interdependence is an important basis for all studies attempting to characterize recession probability, which is an extension of GDP change, as a function of the slope of the yield curve.

Chapter 7

Conclusion

In this thesis, I have attempted to contribute to the existing body of literature regarding the effectiveness of the United States yield curve as a forward-looking macroeconomic indicator. These studies have used a sound theoretical base rooted in yield curve structure for decades, but economic and technological changes over the last 20 years have raised uncertainty as to whether the yield curve is still a reliable economic indicator. Some of the main changes that challenge the yield curve's previously heralded status are the globalization of financial markets including financial innovation, artificial manipulation of interest rates by central banks, and the global savings glut.

I approached the goal of quantitatively analyzing the yield curve's effectiveness by first studying the methods used in existing literature including the probit model and static versus dynamic modeling. I also used conclusions drawn in many previous studies as a base, such as the assumed forecast horizon of 4 quarters and the addition of another yield curve term lagged 6 quarters, which Liu and Moench (2016) found to universally improve probit model fits. I used this framework with multiple yield curve terms throughout my analysis and assessed its effectiveness with McFadden R^2 and log-likelihood values.

In the full sample test, I confirmed Liu and Moench's (2016) results that adding a yield curve term lagged 6 quarters to a yield curve term already lagged 4 quarters increased the fit of probit models. When other explanatory variables were added to the two yield curve terms, the spread of the 5 year Treasury and the Federal Funds rate was most effective, suggesting that markets see an intermediate-term interest rate forecast as the most reliable for a one year forecasting horizon.

In the pre-1995 sample test, I found that the 3 year returns of the S&P 500 index were the most beneficial additional explanatory variable. Since the S&P 500 is only indirectly tied to interest rates, this result may be a product of the changing roles of interest rates and monetary policy prior to the 1990s. Forward guidance may have held less weight compared to today, so equity indices may have been more effective economic indicators. The dynamic models for the pre-1995 samples also performed notably better than the dynamic models for the full sample, suggesting that taking the current state of the economy into account through a lagged binary response variable is important.

In the post-1995 sample test, I unsurprisingly found that the year-over-year percent change in housing starts was the best additional explanatory variable. The second best additional explanatory variable was the spread between the 10 year Treasury and the Federal Funds rate. The use of the Federal Funds rate as the base of the yield curve instead of the 3 month Treasury may be a result of the reduced volatility seen in the Federal Funds rate. Similarly to the pre-1995 sample, dynamic models performed better than static models, especially in cases where the static models were not effective.

VAR analysis of the full sample showed me that the maximum impact of monetary policy was 3 quarters after an impulse in the slope of the yield curve, and that the market's expectations for interest rate hikes are roughly 5 quarters after an impulse in percent change in GDP. These results highlight the fundamental relationship between GDP change and interest rates that should be remembered when conducting any studies attempting to relate the two.

Although each sample provided slightly different results, it seems that the yield curve is still an effective predictor of recessions, especially when combined with other economic variables. The relationship between monetary policy and economic performance through interest rates is a fundamental one that has persisted for decades. As long as monetary policy is conducted primarily using interest rates and the forward guidance of central banks like the Federal Reserve is trusted, I expect that the yield curve will continue to serve as an important and reliable forward-looking economic indicator.

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