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PREDICTING INFLATION

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ABSTRACT

The main purpose of this paper is to analyze the accuracy of three main kinds of forecasts of CPI-U (Inflation) in the United States since 1982: Arbitrage-Free Model, Survey Models, and Statistical Models. After analyzing the accuracy of the three models to predict CPI-U we found:

1. The statistical model ARMA (1,1) has significant predictive capabilities, which challenges the predictive power of professionals and experts in the matter.

2. Means are better predictive measures of CPI-U than Medians. Across the board we found that in all the forecasts that have Mean and Medians the Means were always more accurate than the Medians.

3. Arbitrage-Free Models produce the most inaccurate forecasts. This can potentially be attributed to the Liquidity and Inflation Premiums, in addition to the lack of predictive power of Short-Term T-Bills. More study within this topic is necessary to determine arbitrage opportunities within the TIIS Market.

In conclusion, ARMA (1,1) was the best predictor of inflation over long periods of time, using three different frequencies (6 months, 3 months and 1 month). Even though the results were robust, more research on this subject is necessary to arrive at a definite conclusion on which is the best forecast of CPI-U. Specially, we see an increase in accuracy for the Arbitrage Free Model constructed with TIIS.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

To my family, for unconditionally loving me.

To my professors, for having the patience and passion to make me a better person.

To my friends, for pushing me when I was slacking.

To the ones before me and for the ones to come after me.

Thank you.

Chapter 1

1.1 The problem of inflation

Inflation is defined as an increase in the price of goods and services. This currency-eroding force directly affects individuals since the purchasing power of their income and savings decreases as time progresses. To illustrate this problem think about the following example: Joe earns $100 and spends $100 every month. Suddenly the average price of goods and services rise significantly while Joe's earnings stay at the same level. Joe feels very unhappy because this change in prices does now allow him to be able to purchase as many goods and/or services. This example illustrates how inflation erodes the currency purchasing power, which could potentially lower the quality of life of agents in an economy.

To further illustrate this point please look below:

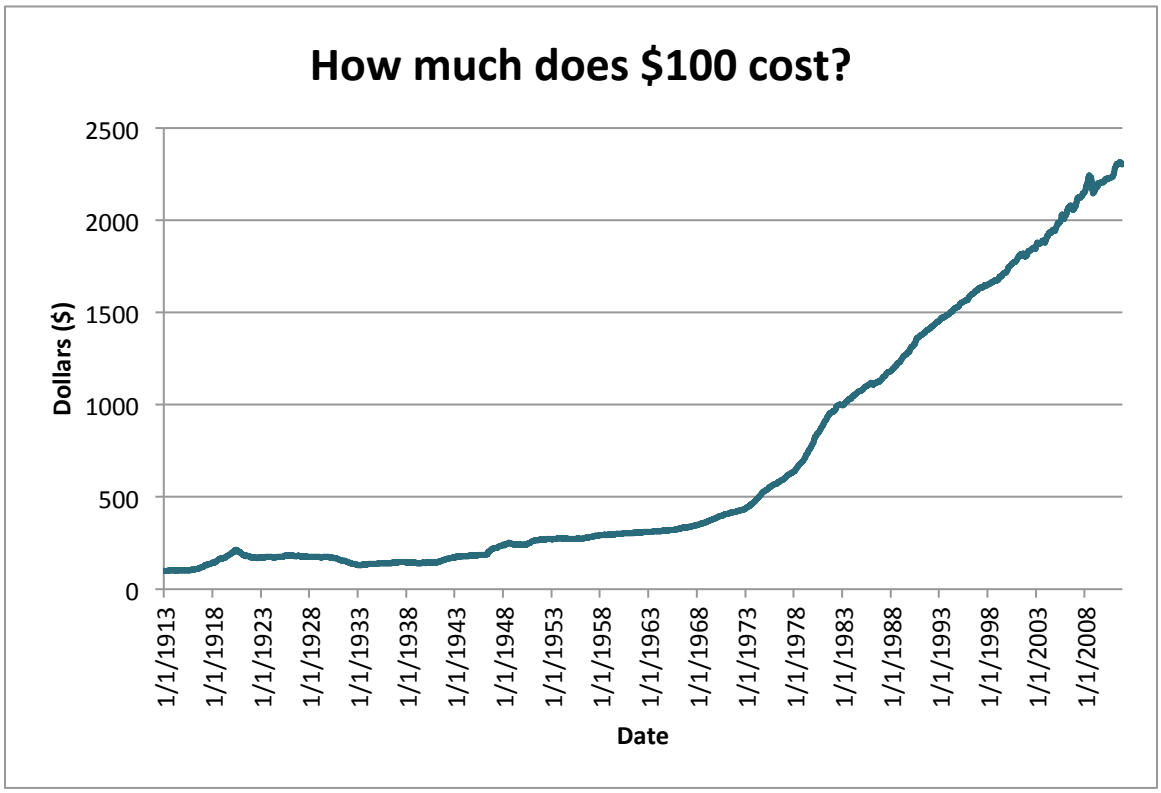

Figure 1.1: How much does $100 cost since 1913?
Source: Bureau of Labor Statistics

This image reflects the fluctuation in purchasing power of $100 since 1913. This chart implies that today somebody would need to spend more than $2,300 for what in 1913 used to cost only $100. Another way interpret the chart is that if $100 would've grown at the inflation rate; the investment would be worth more than $2,300 today.

Having the ability of accurately forecasting inflation is not only useful for individuals, but also for corporations and policymakers. For example, if Corporation X knows that the inputs for its products will rise significantly over the next year, it could make immediate purchases of the product before it becomes expensive. In the case of policymakers, imagine that Ben Bernanke, the Chairman of the Federal Reserve knows that inflation will be very high in the next

year. This piece of information would change The Federal Reserve Monetary Policy to selling government securities such as treasuries in order to decrease the amount of currency in the markets, slowing down the economy to avoid hyperinflation.

After briefly explaining the usefulness of predicting inflation, we need to investigate if predicting inflation is possible. So far we have evidence that forecasts can be used to predict certain macroeconomic variables. In 2004 Ang, Piazzesi and Wei showed that Arbitrage-Free models produced very accurate forecasts of GDP (Gross Domestic Product) growth. Gross Domestic Product is the aggregate goods and services produced in a country within a year. In a later section in this paper we will analyze specific ways to forecast inflation and test their accuracy.

Even though forecasts can be used to predict GDP accurately we do not know if inflation can be accurately forecasted. In order to be able to answer this question it is important to first understand what measure of inflation we want to predict accurately over different periods time.

1.2 Measure of Inflation

Currently there are several measures of inflation used in different parts of the world. Even though these measures do not differ drastically one from another, we need to explain which measure of inflation will be used and the reasons why it has been chosen. This will allow us to determine which forecasts we will use.

In this paper we will use the United States popular measure of inflation called The Consumer Price Index (CPI). The CPI is a measure of the average change over time in the prices of a basket of goods and services purchased by the average consumer. These different items are

weighted according to the proportion of income spent by US citizens. For example: Imagine that on average the consumers of the United States consume products with the following breakdown:

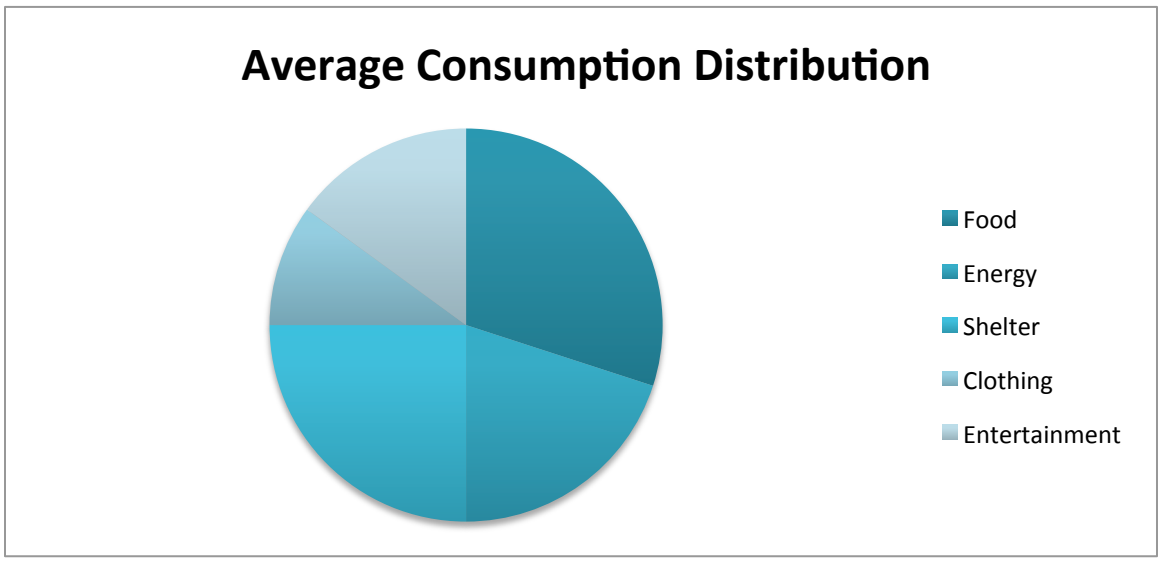

Figure 1.2: Average Consumption Distribution

The following table shows the breakdown and the prices of each category. In case we show how to create the first index of inflation by weighting the prices by the breakdown of average consumption. (Multiplying prices times breakdown)

Categories	Breakdown	Prices	Prices * Breakdown
Food	30	10	300
Energy	20	10	200
Shelter	25	10	250
Clothing	10	10	100
Entertainment	15	10	150
Index (Sum of Prices*Breakdown)			1000

Table 1.1: Consumption of Breakdown and Index generation

The reason why it is important to understand how an index is created is because if the weights change (consumer behaviors) or the types of prices recorded change (if the methodology is different), the inflation measure could be drastically different. In other words, comparing

different measures of inflation across different countries, different prices and/or different methodologies can create an unfair comparison.

Currently there are three different CPI series. This paper will only focus on CPI-U because, as it will be explained below, CPI-U is considered to be the higher band for inflation (it is very unlikely to underestimate inflation) and also it is considered to be the most inclusive and widely used measure of inflation for forecasts.

1.2.1 The CPI-U

The Bureau of Labor Statistics first published the CPI-U in January 1978; it represents the average change in price of products consumed by the residents of urban areas in the United States. The percentage change in the index level over two periods represents the overall level of inflation between those periods:

$$Inflation = \frac{Index\ Level\ (Final) - Index\ Level\ (Beginning)}{Index\ Level\ (Beginning)}$$

CPI-U is a Laspreyes index, which means that it does not take into account that when prices rise, quantity demanded usually decreases. Therefore it is said that the CPI-U might provide an "upper bound" on the Cost of Living Index (COLI). What this means is that CPI-U is more likely to reflect inflation higher than other measures. Therefore, when we use CPI-U the risk of underestimating inflation is reduced.

Why not Core CPI?

CPI-U was used instead of "Core CPI" mainly because individuals care about the overall level of inflation including food and energy. Core CPI can be useful for policy-makers and certain investors that want to have a clear view of inflation once volatile prices (such as food and energy) have been removed. Unfortunately this measure is not very informative for most citizens since they are interested in the overall level of prices including every item regardless of how volatile it can be. In other words, when Joe spends money he feels the increase or decrease of price in items such as food and energy. For more information on this topic read the article "Measuring Inflation: The Core is Rotten" by James Bullard.

The following image reflects the inflation rate as measured by the CPI-U:

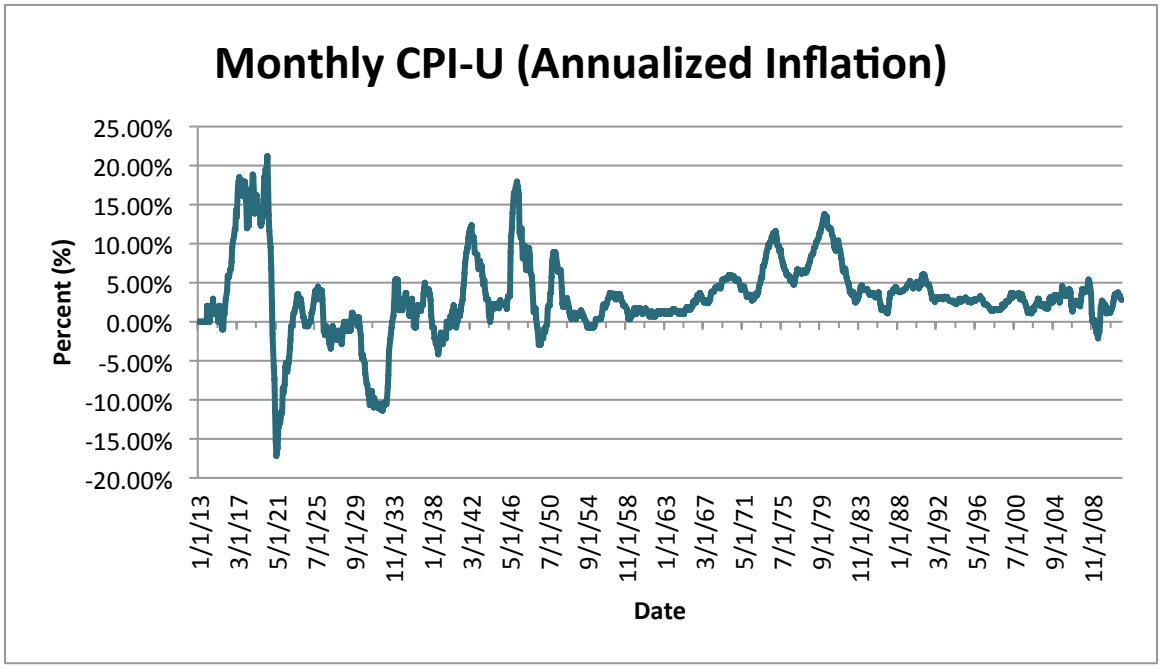

Figure 1.3: Monthly CPI-U (Annualized)
Source: Bureau of Labor Statistics

Chapter 2

2.1 Forecasts of CPI-U

There has been a considerable amount of research on which is the most reliable and accurate forecast of CPI-U. In 1999 Stock and Watson found that the most accurate forecast of inflation up to 1996 were the Phillips Curve-based forecasts. Unfortunately this study was rather narrow and did not consider Arbitrage-Free, Survey and Statistical Model forecasts. Additionally there has been criticism about the robustness of Stock and Watson findings. In Cechetti, Chu and Steindel (2000), Atkeson and Steindel (2001), Fisher, Liu and Zhou (2002) and Sims (2002), pointed out that the accuracy of Phillips curve-based forecasts depend largely to the sample period. This is why we will not use Phillips Curve Model Forecasts to predict CPI-U.

The most comprehensive study made so far was made in 2006 by Ang, Bekaert and Wei titled: "Do Macro Variables, Asset Markets, or Surveys Forecast Inflation Better?" The finding of this study is that surveys are the best predictors of CPI-U after considering Phillips Curve-based forecasts, term structure models that include linear, non-linear and Arbitrage-Free specifications and time series-ARIMA models. It is important to consider that this paper was made 6 years ago and its important to incorporate new points of data that could dramatically change the findings of that paper.

Another important study to consider is Meyer and Pasaogullari called "Simple Ways to Forecast Inflation: What Works Best?" (December, 2010). In this study many forecasts of inflation were generated using many different processes and the forecasts were compared to the actual level of inflation. The conclusion was that there is no single specification that may

outperform during all periods. While the Median and 16% Trimmed-Mean measures outperform all other specifications during the 1990's, survey-based inflation expectations outperform during volatile periods. Meyer and Psaogullari's paper is very robust in terms of calculations and the breadth of forecasts taken into consideration. To provide comparable findings, we incorporate many kinds of models that can produce forecasts and we also compare over different time frequencies.

Forecasting Models:

1. Market-Based Models
    - 1.1 Arbitrage-Free model
    - 1.2 Short-Term T-Bills
    - 1.3 Composite 1-Year
2. Surveys
    - 2.1 Livingston
    - 2.2 Michigan
    - 2.3 Survey of Professional Forecasters
3. Statistical Models
    - 3.1 Mean-Trimmed Model
        - 3.1.1 5% Trimmed Mean
        - 3.1.2 10% Trimmed Mean
        - 3.1.3 15% Trimmed Mean
    - 3.2 ARMA (1,1) Model

2.2 Forecasts Timing

After finding forecasts of the same macroeconomic variable (CPI-U in this case), there are three different factors that need to be consider with respect to timing:

1. Frequency
2. Time Span
3. Initial Pont

2.2.1 Frequency

The following table illustrates the Frequency of the forecasts compared in this study:

Model	Frequency
1. Market-Based Models	
1.1 Arbitrage-Free model	Daily
1.2 Short-Term T-Bills	Daily
1.3 Composite 1-Year	Daily
2.Surveys	
2.1 Livingston	Quarterly
2.2 Michigan	Monthly
2.3 Survey of Professional Forecasters	Semiannual
3.Statistical Models	
3.1 Mean-Trimmed Model	
3.1.1 5% Trimmed Mean	Monthly
3.1.2 10% Trimmed Mean	Monthly
3.1.3 15% Trimmed Mean	Monthly
3.2 ARMA (1,1) Model	Monthly

Table 2.1: Frequency

2.2.2 Time Span

Time Span refers to the differences in the time over which CPI-U being forecasted. Bellow is a table that shows the time span that different forecasts can include.

Model	Time Span
1. Market-Based Models	
1.1 Arbitrage-Free model	1, 2, 5, 7 and 10 years
1.2 Short-Term T-Bills	3 months, 6 months and 1 year
1.3 Composite 1-Year	1 year
2.Survey	
2.1 Livingston	1 year
2.2 Michigan	1 year and 10 years
2.3 Survey of Professional Forecasters	1 year and 10 years
3.Statistical Models	
3.1 Mean-Trimmed Model	
3.1.1 5% Trimmed Mean	1-12 months
3.1.2 10% Trimmed Mean	1-12 months
3.1.3 15% Trimmed Mean	1-12 months
3.2 ARMA (1,1) Model	1-12 months

Table 2.2: Time Span

2.2.3 Initial Point

The forecasts of CPI-U have different initial points of data:

Model	Span
1. Market-Based Models	
1.1 Arbitrage-Free model	1/1/07
1.2 Short-Term T-Bills	2/1/82
1.3 Composite 1-Year	2/1/81
2. Surveys	
2.1 Livingston	6/1/72
2.2 Michigan	1/1/79
2.3 Survey of Professional Forecasters	12/1/82

3.Statistical Models		
	3.1 Mean-Trimmed Model	
	3.1.1 5% Trimmed Mean	12/1/77
	3.1.2 10% Trimmed Mean	12/1/77
	3.1.3 15% Trimmed Mean	12/1/77
	3.2 ARMA (1,1) Model	12/1/77

Table 2.3: Initial Point

2.2.4 Solutions to the Timing Issues

Clearly all of these different timing issues have to be addressed in order to have fair comparative measures of the accuracy of different predictors of inflation. This is the solution for each of the following issues:

1. Frequency: Forecasts accuracy is analyzed every six months, three months and one month.
2. Time Span: The only span that will be taken into consideration will be the 1-year time span. The two reasons for this decision are:
    a. The 1-year span is the most popular amongst all forecast models
    b. According to a paper titled: "Discussion of the Survey of Professional Forecasters' Long-Term Forecast for Inflation " by Tom Stark (June 2004); when long-term predictions were used (10 years or more) they tend to be inaccurate. This was explained since the forecast has little variability even though individual forecasters have changed their expectation more frequently than what is observed.
3. Initial Points will be adjusted to the most recent useful forecast within at least one kind of forecasting model. For example: In the case of Market-Based Forecasts, the

Arbitrage-Free Model could be discarded in case that the composite 1-Year model is useful to describe the market inflationary expectations

In the following three chapters (Chapter 3, Chapter 4 and Chapter 5) we will discuss the three models used to produce forecasts of inflation.

Chapter 3

3.1 Arbitrage-Free Model

An Arbitrage-Free model is one where, as the name suggests, the main assumption is that there is no possibility of arbitrage. Arbitrage is defined as having a chance of making a riskless profit. In our case, we assume is that there is no possibility of profiting from either buying or selling Nominal Treasury Bonds and selling or buying Treasury Inflation Indexed Securities (TIIS, commonly referred as TIPS) with the same maturity. This point will be illustrated more explicitly once certain terms are defined.

3.1.1 Nominal Treasury Bonds

In essence, Nominal Treasury Bonds are loans to the Department of Treasury of The United States of America. In this loan, The Treasury promises to repay the principal (at maturity) plus pay a fixed amount of interest to the investor (semi-annual coupons). The Nominal Treasury Bonds are regarded as one of the safest investments in the world since they are backed by the government of the largest economy in the world (in GDP terms). During 2012 the risk of default (the government not repaying its loan) on US Treasuries during the next year is lower than one in a thousand.

3.1.2 TIIS

Treasury Inflation Indexed Securities (TIIS) are bonds issued and protected by The Treasury of The United States of America. TIIS were first issued in 1997. Currently the Treasury offers TIIS with 5, 10 and 10-year maturities. These can be purchased at auctions or through a broker. TIIS have different maturities and different fixed semiannual coupons depending on when they were issued (if they were issued in a period of low interest rates it is more likely to find lower issues with lower coupons). Their principal value fluctuates based on the CPI-U Index; therefore there is a three-month lag (Ex. The CPI-U for Jan affects the principal value of the TIIS in April). If there is an increase in the CPI-U Index, the principal will grow in accordance to the percentage increase in the CPI-U Index and coupons will be calculated based on this new principal value. If there is a decrease in the CPI-U Index, the principal value will decline and the new coupons will be calculated using the lower principal. However, even if the principal value falls under 100 as a result of deflation the Treasury will always pay the holder of the security 100 at maturity. Therefore the maturity value of the bonds can never be less than 100.

3.1.3 No-Arbitrage

Assuming that there is no arbitrage between nominal and inflation indexed securities, their yields on issues with the same maturity should be the same once we adjust for the liquidity and inflation premiums. The liquidity premium is the benefit that holders of illiquid securities receive, and the inflation premium is the cost of buying protection against inflation risk. We will

assign the symbol P_L and P_I for the liquidity and inflation premiums respectively (in absolute terms) and arrive at the following formula for the Arbitrage-Free model.

$$Y_N = Y_{TIIS} + |P_L| - |P_I| + \Pi_{Expected} \quad (1)$$

The Inflation premium is the value that investors are willing to pay in order to purchase a security without inflation risk. The liquidity premium is the value that investors get paid in exchange for holding an instrument that can hardly be converted to cash.

Where Y_N and Y_{TIIS} are the annual yields on nominal treasuries and treasury inflation indexed securities respectively. Π represents the expected annual average inflation until maturity.

After re-arranging formula (1) we obtain:

$$Y_N - Y_{TIIS} - |P_L| + |P_I| = \Pi_{Expected} \quad (2)$$

We know that:

$$Y_N - Y_{TIIS} = Y_R \text{ (Real Yield)} \quad (3)$$

Therefore,

$$Y_R - |P_L| + |P_I| = \Pi_{Expected} \quad (2+3)$$

3.1.4 Finding the variables

Real yield (Y_R)

Currently the most reliable source for the Real Yield (Y_R) is the United States Treasury webpage. The 5, 7 and 10 Year Real Yields are computed daily since the February 1st, 2003. These rates are commonly referred to as "Real Constant Maturity Treasury" rates, or R-CMTs. Real yields on Treasury Inflation Protected Securities (TIPS) at "constant maturity" are interpolated by the U.S. Treasury from Treasury's daily real yield curve. These real market yields are calculated from composites of secondary market quotations obtained by the Federal Reserve Bank of New York. Additionally we can consider using the closest 1-Year TIIS Yield and subtract the 1-Year Nominal Treasury Bond.

The following table reflects the 5-Year Real Constant Maturity Rate Vs. the CPI-U (annualized)

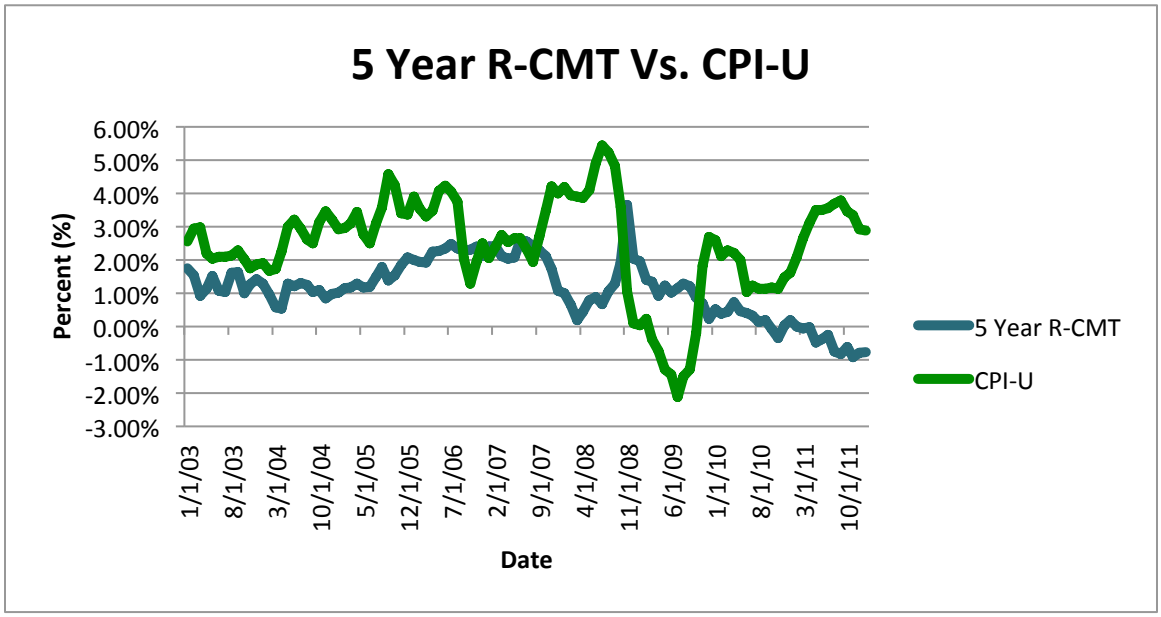

Figure 3.1: 5-Year Real Rate Vs. CPI-U
Source: US Treasury

In Bloomberg there are two economic indexes that are used in this study. They are:

- USGGBE01 Index
- USGGBE02 Index

These indexes reflect the daily breakeven inflationary rate in the United States for 1 and 2 years. These are calculated by subtracting the yield on a Nominal Treasury Bond and the Treasury Inflation Indexed Bond with the same maturity. After performing this calculation the market implied inflation rate is obtained.

The table bellow illustrates the CPI-U Vs. the Breakeven Rates:

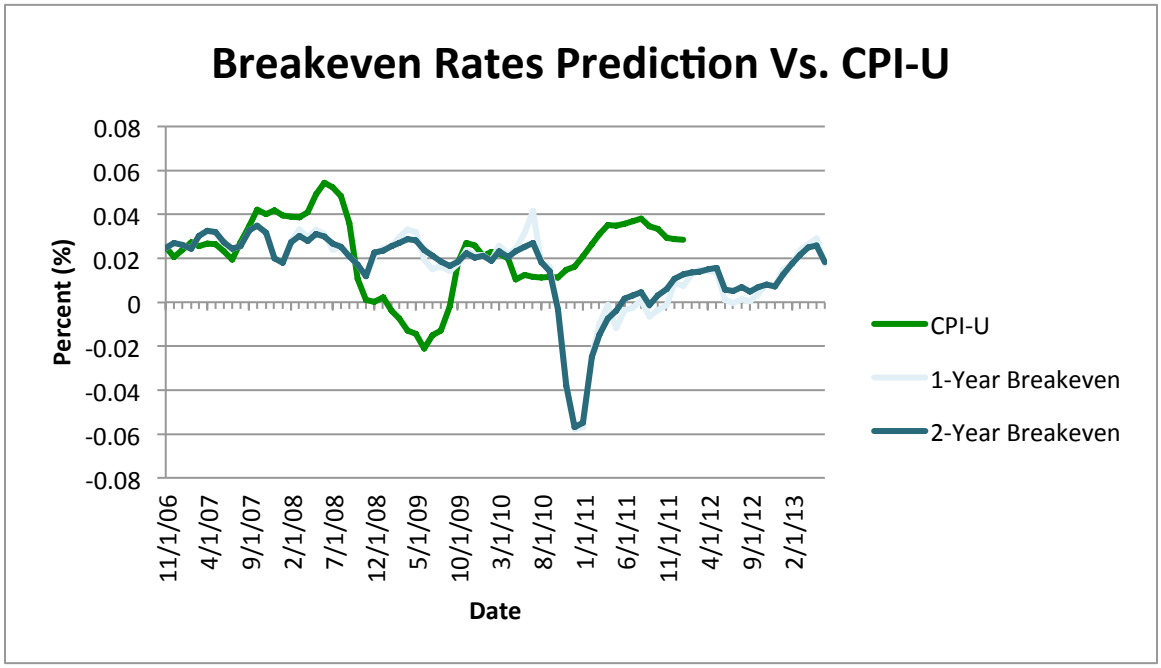

Figure 3.2: US Breakeven Rates Vs. CPI-U
Source: Bloomberg

Liquidity (P_L) and Inflation Premiums (P_I)

There have been several studies that have made attempts to quantify the magnitude of the liquidity premium. TIIS have been less liquid than nominal treasury bonds historically although currently they represent close to 8% of the trading volume of all treasury notes. Therefore the premium that investors received for the lack of liquidity has come down in the recent year, with exception of events such as the credit crisis in 2008.

In a paper by Christen and Gillan (2011) from the Federal Reserve Bank of San Francisco called "A Model-Independent Maximum Range for the Liquidity Correction of TIPS Yields" it says the following: "While we do not seek to peg down the precise level of the TIPS liquidity premium, we provide evidence in support of it being closer to the bottom half of the range. In particular, the estimated deflation probabilities and their implications for the value of the deflation protection embedded in TIPS are considerably more realistic when TIPS are considered to have no liquidity premium rather than the maximum. This finding provides partial support for the approach taken in papers like Adrian and Wu (2010) and CLR (2010) that use TIPS yields as observed without correcting for the liquidity differentials, but leads us to question the validity of the conclusions and policy recommendations of FLL (2010) whose analysis is based on the implicit assumption that there are no liquidity premiums in the inflation swap market."

This finding is central to this paper since we will not try to estimate these measures when we decide to compare the accuracy of market forecasts of CPI-U.

3.2 Short-Term T-Bills

The United States Treasury issues bonds that mature in 1 year or less. These bonds are traded in secondary markets and they can sometimes reflect inflationary expectations. Recall that the Real Return of an asset is affected by inflation. As defined by Fisher's Equation:

$$Y_N = R + \Pi_{Expected}$$

Where Y_N is the Nominal Rate, R is the Real Rate and $\Pi_{Expected}$ is the expected level of inflation during the period.

Most rational investors do not wish to invest at a negative real return. This is why investors may demand higher short-term interest rates if inflation rate is high. Conversely, if the gap between inflation and short-term interest rates is too high, investors will demand more Treasuries, pushing the short-term interest rates down.

The two main problems of using Short-Term T-Bill Yields as a forecast for CPI-U are the following:

1. 0-Bound: Negative Yields on T-Bills suggest that individuals are paying somebody to hold on to their investment (please, hold on to my cash, I'll even pay you). This is why bonds usually do not remain at negative levels except for a very brief period of time. We know that inflation rates can become negative; therefore short-term interest rates cannot predict future deflation (a decrease in the price of goods and services).
2. Federal Reserve Monetary Policy: Short Term Interest Rates in the United States are heavily influences by the Federal Reserve Monetary Policy. Since the Federal Reserve has kept the FED's Fund rate at, or near 0%, short-term

interest rates have plunged and stayed at historically low levels even though inflation has been higher than 1.5% (annualized) for the past year. This is the second reason why Short-Term T-Bills may not predict future inflation accurately.

The following table represents the yield of the 3-mo, 6-mo and 1-Year Treasury Bill and also the annualized inflation rate measured by the CPI-U.

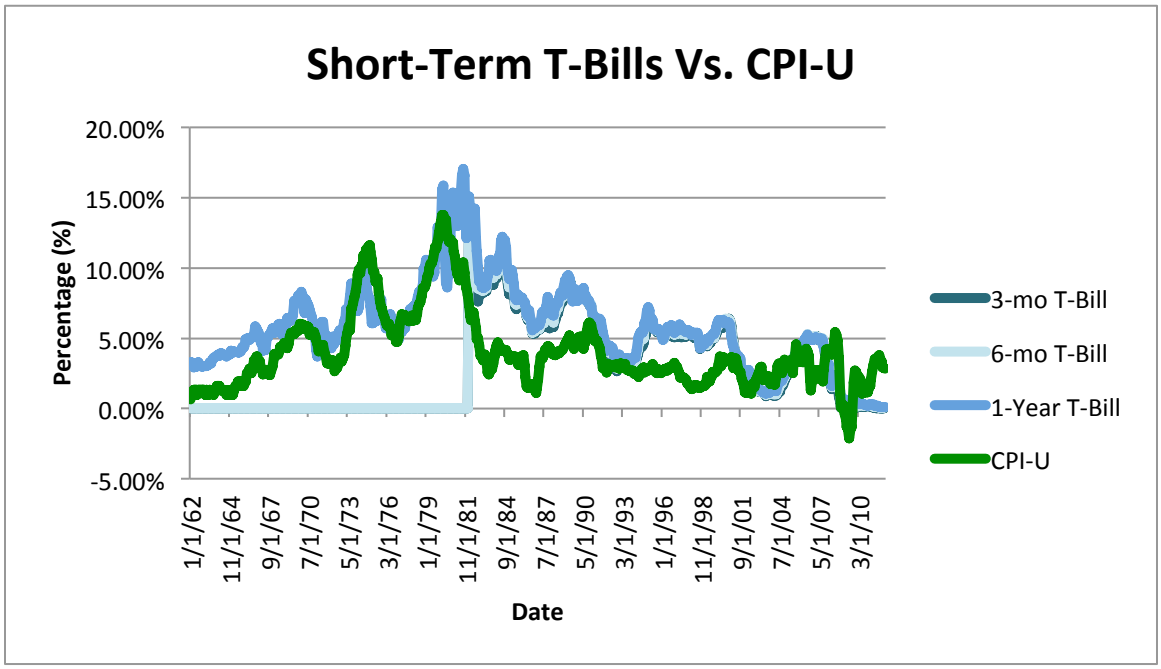

Figure 3.2: Short-Term T-Bills Vs. CPI-U
Source: US Treasury

3.3 Composite 1-Year Market-Expected Inflation

The Composite 1-Year Market-Expected Inflation is the combination of the Arbitrage-Free Model and Short-Term T-Bills. The reason why these two methods were merged was

because of the starting point differences and the accuracy. These were the benefits of each of the series:

- Including T-Bills increased the number of observations significantly since its starting point is more than 115 years before the Arbitrage-Free Model.
- Including the Arbitrage-Free Model increased the accuracy of predictions

These two methods can produce the longest and most effective historical market inflation expectations.

Constructing this model we decided to include, when available with the following priority order:

1. 1 year US Breakeven Index
2. 2 year US Breakeven Index
3. 5 year US Constant Maturity Real Rate
4. 3 month Treasury Bill

This combination generated the 1-Year Composite, which can be seen here compared to CPI-U:

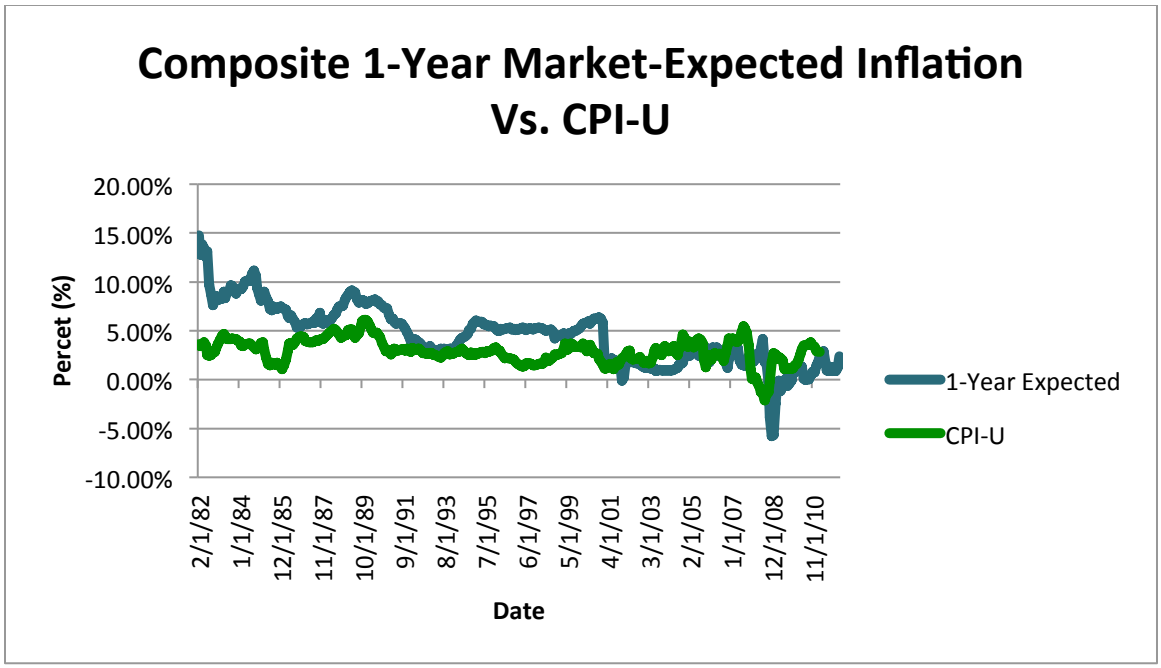

Figure 3.2: Composite 1-Year Market-Expected Vs. CPI-U

Chapter 4

4.1 Surveys

Surveys represent the collection of responses of different individuals. We will analyze three different surveys that provide forward-looking forecasts of CPI-U:

1. Survey of Professional Forecasters (SPF)
2. The University of Michigan Household Forecast of Inflation Survey (Michigan)
3. Livingston Survey

4.1.1 Survey of Professional Forecasters (SPF)

The Survey of Professional Forecasters is the oldest quarterly survey of macroeconomic forecasts in the United States. The survey began in 1968 and was conducted by the American Statistical Association and the National Bureau of Economic Research. The Federal Reserve Bank of Philadelphia has been in charge of producing the survey since 1990.

CPI-U is one amongst the different macroeconomic variables forecasted by the SPF. This survey contains two different forecasts of CPI-U:

1. One-year-ahead CPI-U forecasts
2. 10-Year average annual CPI-U forecasts

The expected annualized inflation in the next twelve months is expressed in annual averages, in annualized percentage points. These data are specified for each of the next four quarters, beginning with the quarter after the quarter in which the survey was conducted.

The following image reflects the Mean and Median SPF forecasts of Annualized CPI-U versus the actual CPI-U.

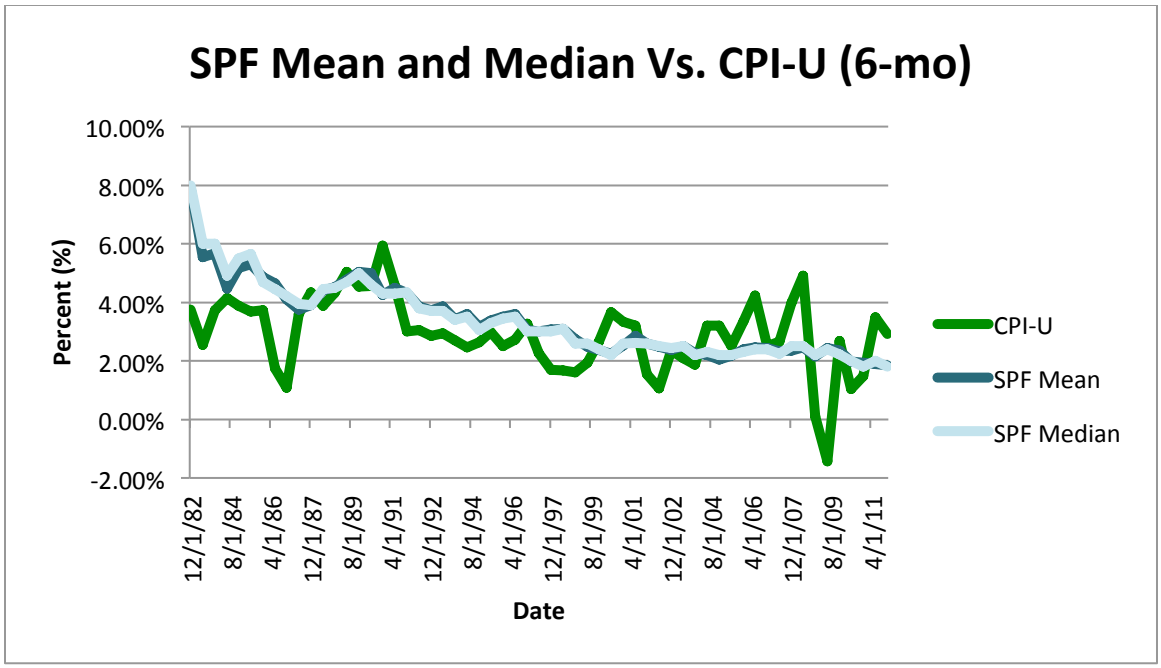

Figure 4.1: Mean and Median SPF Prediction Vs. Actual CPI-U

4.1.2 The University of Michigan Household Forecast of Inflation Survey

The monthly Reuters/University of Michigan Surveys of Consumers gauge how consumers feel the economic environment will change. Survey results are released twice each month at 10:00 AM Eastern Time:

1. Preliminary Estimates: Usually on the second Friday of each month
2. Final Results: On the fourth Friday of each month

The next twelve month CPI-U (annualized) is among the different economic variables that individuals are surveyed every month. Values for the Mean and Median in addition to different percentiles are reported.

The following image reflects the Mean and Median Michigan forecasts of Annualized CPI-U versus the actual CPI-U.

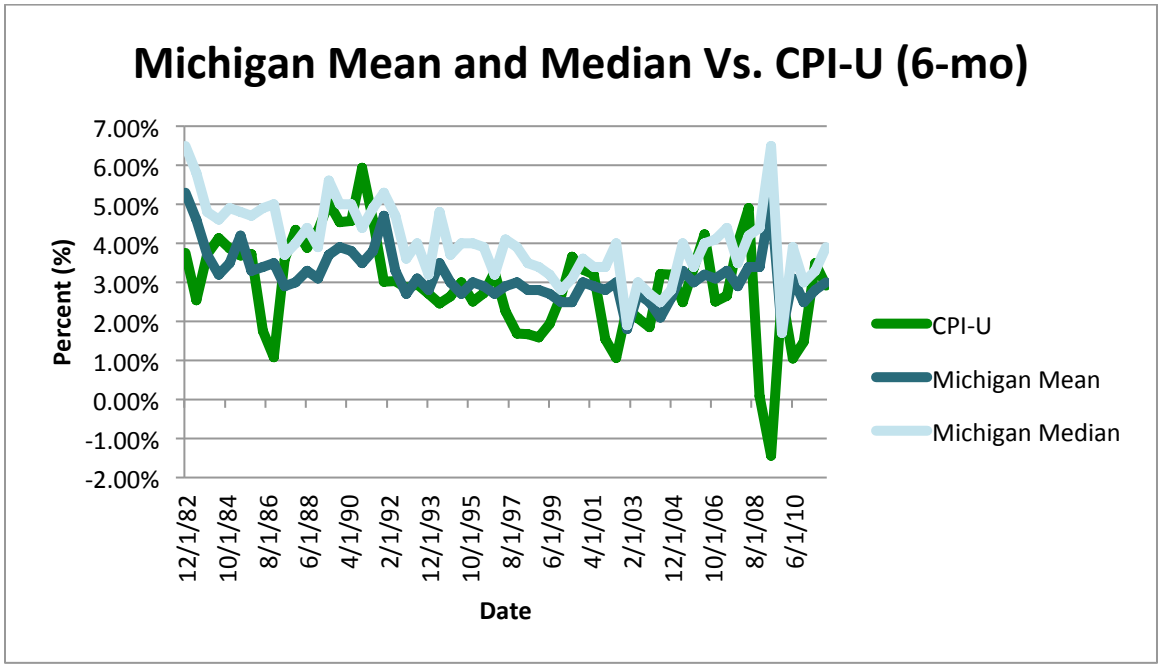

Figure 4.2: Mean and Median Michigan Prediction Vs. Actual CPI-U

4.1.3 The Livingston Survey

The Livingston survey is conducted semiannually, in June and in December, and polls economists from industry, government, and academia. The Livingston survey records participants' forecasts of non-seasonally-adjusted CPI levels six and twelve months in the future and is usually conducted in the middle of the month. The SPF is conducted in the middle of every quarter and the sample period for the SPF Median forecasts is from 1981:Q3 to 2012:Q4.

The following image reflects the Mean and Median Livingston survey forecasts of Annualized CPI-U versus CPI-U.

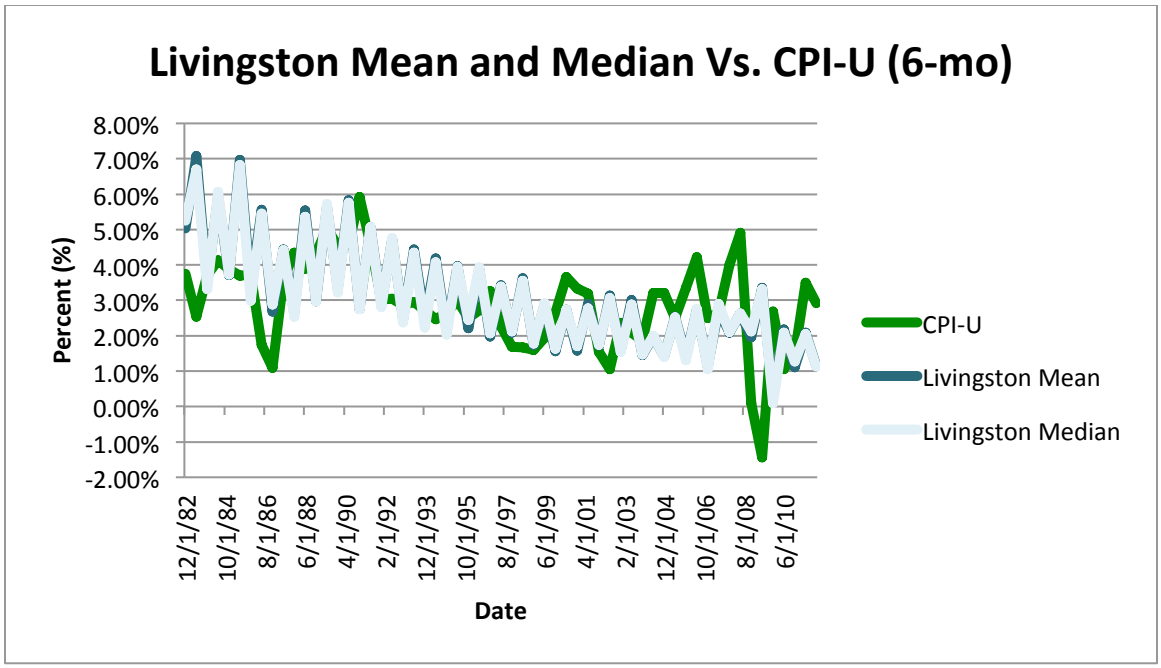

Figure 4.3: Mean and Median Livingston Prediction Vs. Actual CPI-U

4.1.4 Considerations

On surveys lags

There is a reporting lag of a week in SPF and Livingston, which is irrelevant for predictive purposes.

Special Considerations

Nevertheless, it is very important to understand the special considerations of each survey:

Livingston Survey: Forecasters presumably use information up to at most the beginning of June and December, and most do not have the May and November official CPI numbers.

SPF: Forecasts can only use information up to at most the middle of the quarter.

Survey Name	Questionaire sent to panelists	Last set of information in the Quationaire	Deadline for submission	Results Release Date
First Quarter	End of January	Q4	Middle of February	Middle to Late February
Second Quarter	End of April	Q1	Middle of May	Middle to Late May
Third Quarter	End of July	Q2	Middle of August	Middle to Late August
Fourth Quarter	End of October	Q3	Middle of November	Middle to Late November

Table 4.1: SPF Questionnaire method from Q3 of 1990 to present.

Note that before 1990 it is impossible to know with certainty the timing of the survey but we assume that it was performed in a similar fashion as it is currently.

Michigan: Consumers do not have up-to-date economic data available at the end of the quarter.

Chapter 5

5.1 Statistical Models

As explained in Chapter 2, there have been studies that have used Statistical Models to construct predictions of macroeconomic variables, including CPI-U. Some Statistical Models have predicted inflation very accurately and that is the reason why they are included in this paper. The basic assumption is that we can use historical data of CPI-U to predict future data of CPI-U since inflation cyclical and "sticky" (last period tends to be close to the next period)

5.1.1 Mean-Trimmed Model

The Mean-Trimmed Model is one where the Mean does not consider extreme values. The Mean is defined as the sum of all the events, divided by the number of observations:

$$Mean = \frac{\sum X}{N}$$

The difference between the Mean and the Trimmed Mean is that we eliminate the X's that are at the end of the tails of the distribution. For example: Say we have the following Observations:

5, 7, 8, 3, 10, 15, 35. If we compute the Mean we would sum all of the observations and divide by the number of observations. In this case the Mean would be 11.86. But if instead we calculate the

Mean and decide to eliminate the lowest and the highest number we obtain a Trimmed Mean of 8.6.

For the purpose of the paper we will use the 5%, 10% and 15% Trimmed Means with frequencies of 6 months, 3 months and 1 month to predict the next period's annualized CPI-U.

The Following table reflects the 5%, 10% and 15% Trimmed Means Vs. CPI-U:

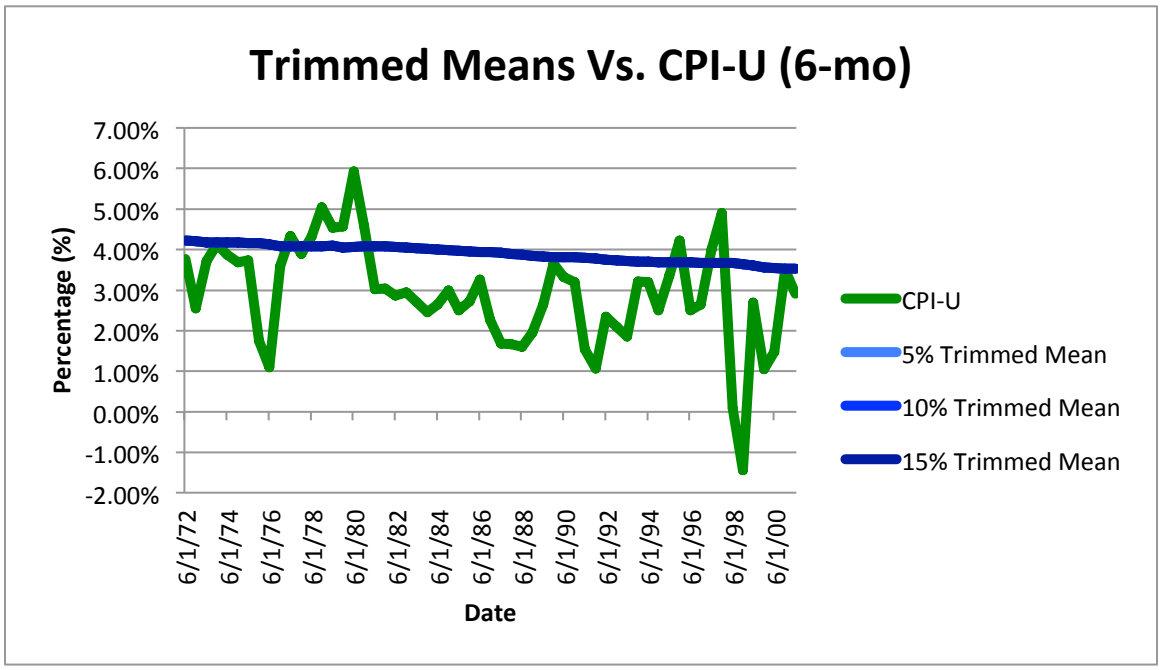

Figure 4.3: Trimmed Means Vs. CPI-U
Note: The 5% and 10% Trimmed means are not visible since they closely follow each other

5.1.2 ARMA Model

The ARMA model is the second statistical model used to predict future inflation using past data of inflation. The model consists of two parts: autoregressive (AR) and a moving average (MA). The model is usually referred to as the ARMA (p, q) model where p is the order of the autoregressive (AR) part and q is the order of the moving average part (MA).

The autoregressive part can be defined by the following equation:

$$X_t = \phi X_{lag} + \varepsilon_t \tag{1}$$

What this equation means is that we expect the future data to be equal to the past data plus an error that is expected to be zero on average.

The moving average part can be defined by the following equation:

$$X_t = \mu + \varepsilon_t + \theta \varepsilon_{t-1} \tag{2}$$

Then we can combine these two equations to get ARMA (1,1) model:

$$X_t = \mu + \varepsilon_t + \theta \varepsilon_{t-1} + \phi X_{lag} + \varepsilon_t \tag{1+2}$$

As explained before, the scope of this paper includes three frequencies: 6-Months, 3-Months and 1-Month. Now that we have defined the formula it is important to make sure that the right parameters (p, q) are used for each of the intervals. In order to find p and q we perform an autocorrelation plot and a partial autocorrelation function for each of the frequencies.

6-Months:

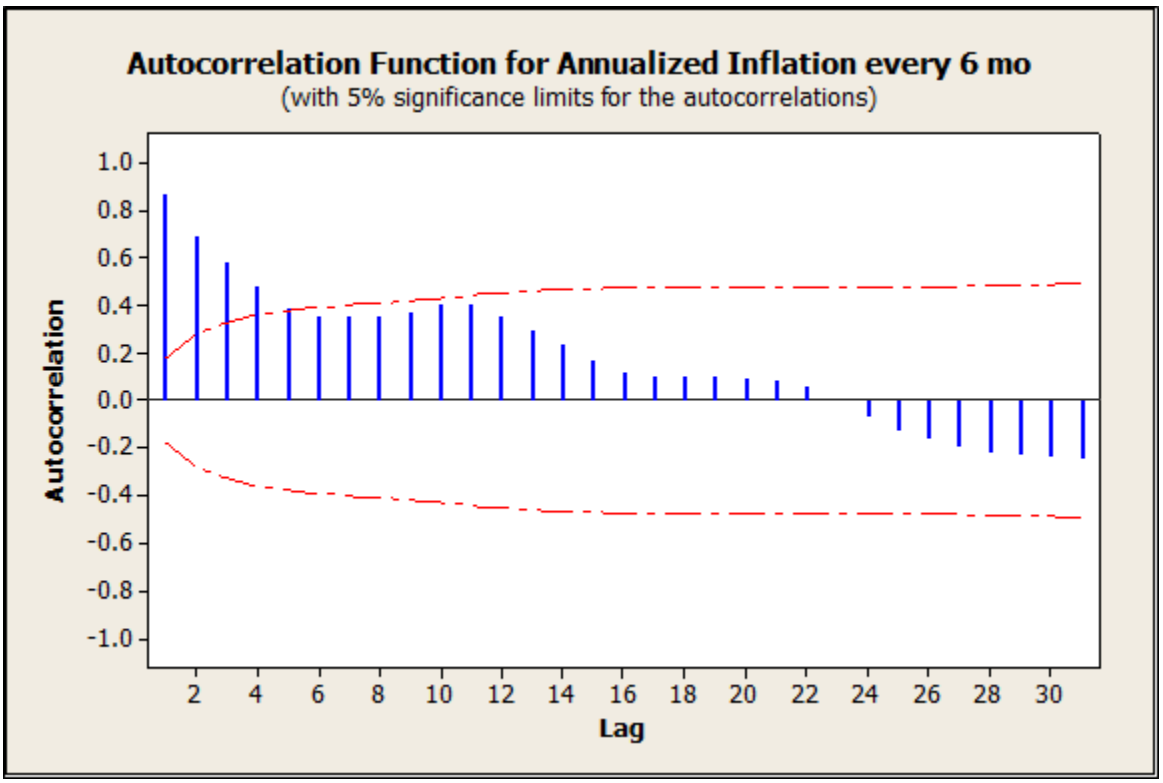

Figure 5.1: Autocorrelation Function for 6-MO Inflation
Source: Minitab

The following plot clearly shows that a lag of 1 has the highest level of autocorrelation.

Therefore the most appropriate p is 1 (lag of 1)

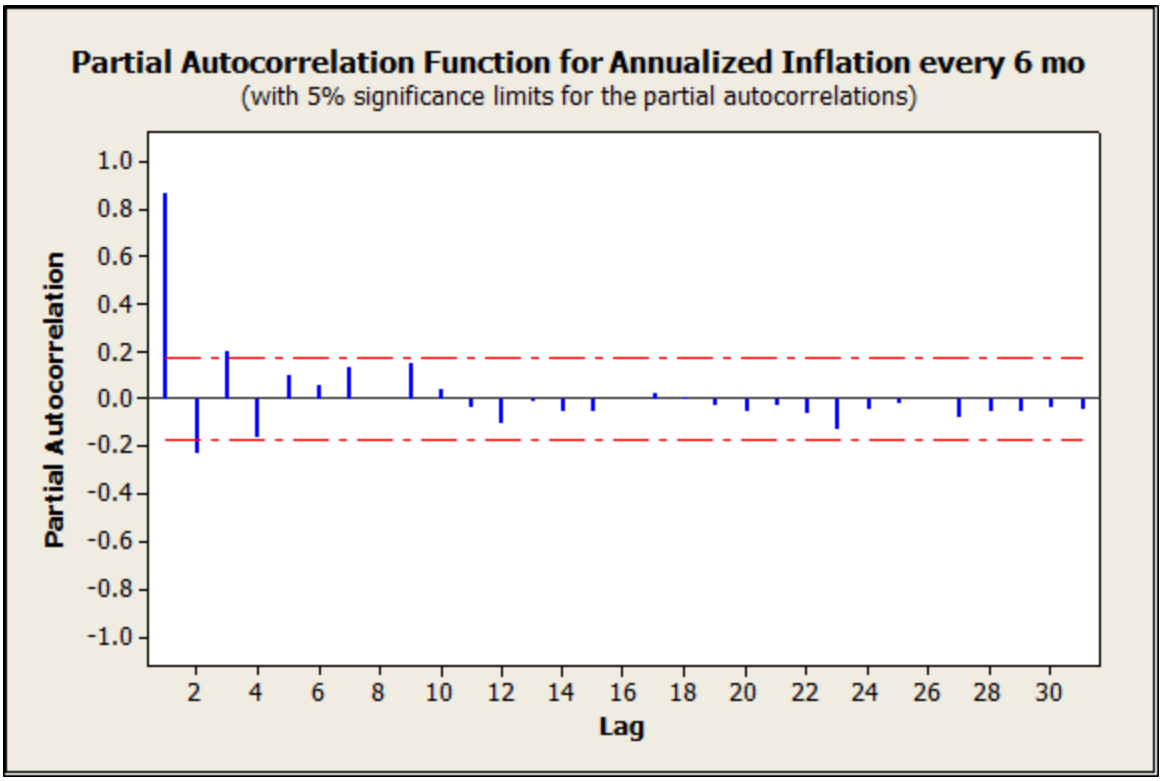

Figure 5.2: Partial Autocorrelation Function for 6-MO Inflation
Source: Minitab

The following plot clearly shows that a lag of 1 is the most appropriate to use since it has the highest level of partial autocorrelation. It is important to notice that a lag of 2 and 4 could also be used since they are significant. However, only a lag of 1 will be used since it produces the most accurate forecasts of inflation (q=1).

Since p and q will be equal to 1, this creates what is called the ARMA (1,1) model. This is the model from which we will create inflation forecasts and compare its accuracy to other forecasts.

During the 3 and 1-Month periods the same logic applies, as it is evident in figures 5.3-5.6:

3-Months:

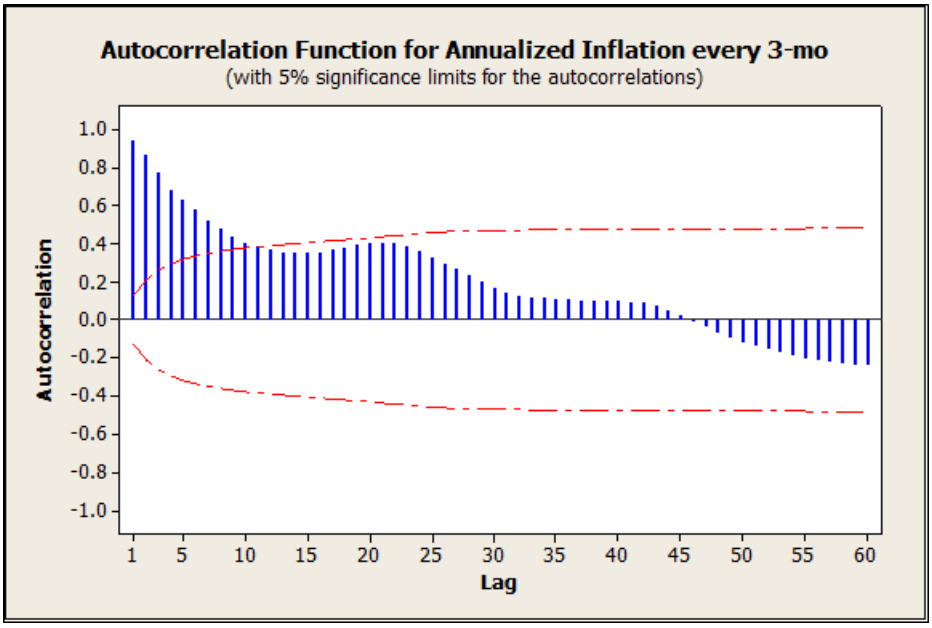

Figure 5.3: Autocorrelation Function for 3-MO Inflation

Source: Minitab

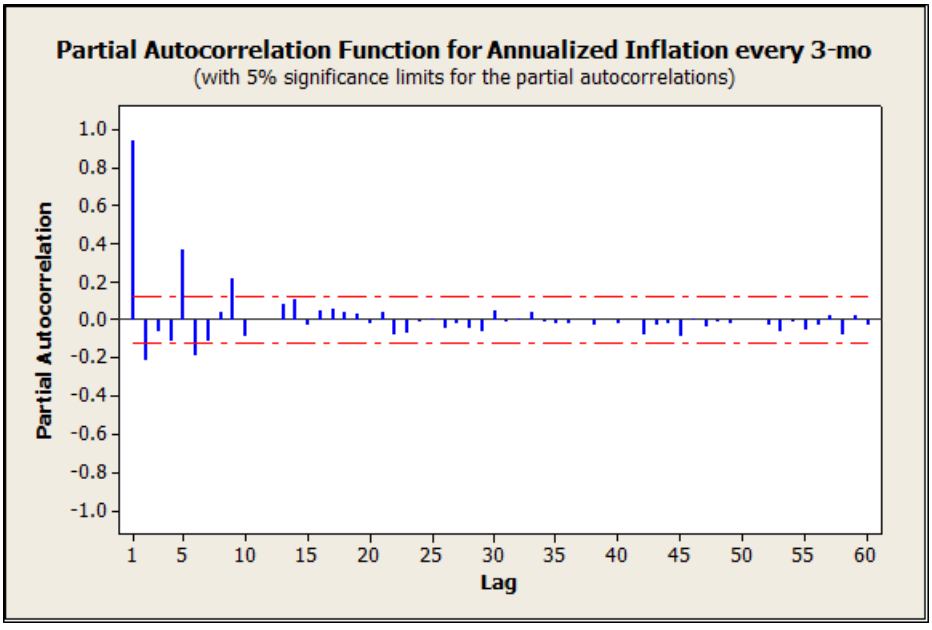

Figure 5.4: Partial Autocorrelation Function for 1-MO Inflation

Source: Minitab

1-Month:

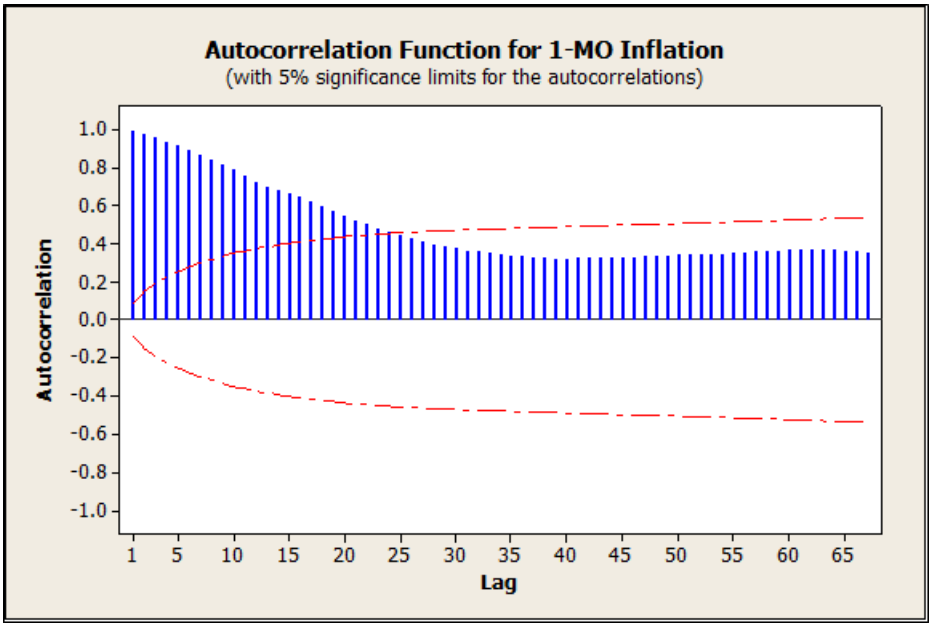

Figure 5.5: Autocorrelation Function for 1-MO Inflation
Source: Minitab

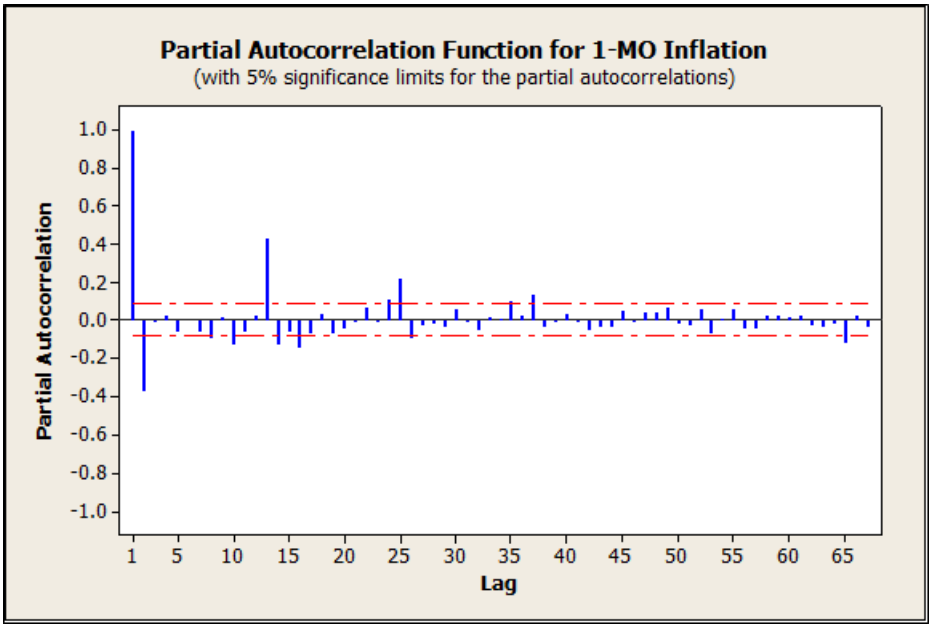

Figure 5.6: Partial Autocorrelation Function for 1-MO Inflation
Source: Minitab

Chapter 6

6.1 Methodology and Results

6.1.1 Methodology

A method to find the most accurate forecast is The Root Mean Squared Deviation (RMSD):

$$RMSD = \sqrt{\frac{\sum_{i=1}^{n} (x_{1,i} - y_{1,i})^2}{n}}$$

These are the following steps to produce the RMSDs:

1. Compute the difference between each of forecast (y) and the realized CPI-U (x).
2. Square this result in order to be able to convert this difference into a positive number.
3. Add these squared differences (also called squared errors).
4. Divide by the number of observations (similar to taking an average).
5. Compute the square root

6.1.2 Results

In the following subsections the results for each of the frequencies will be shown:

6 Months

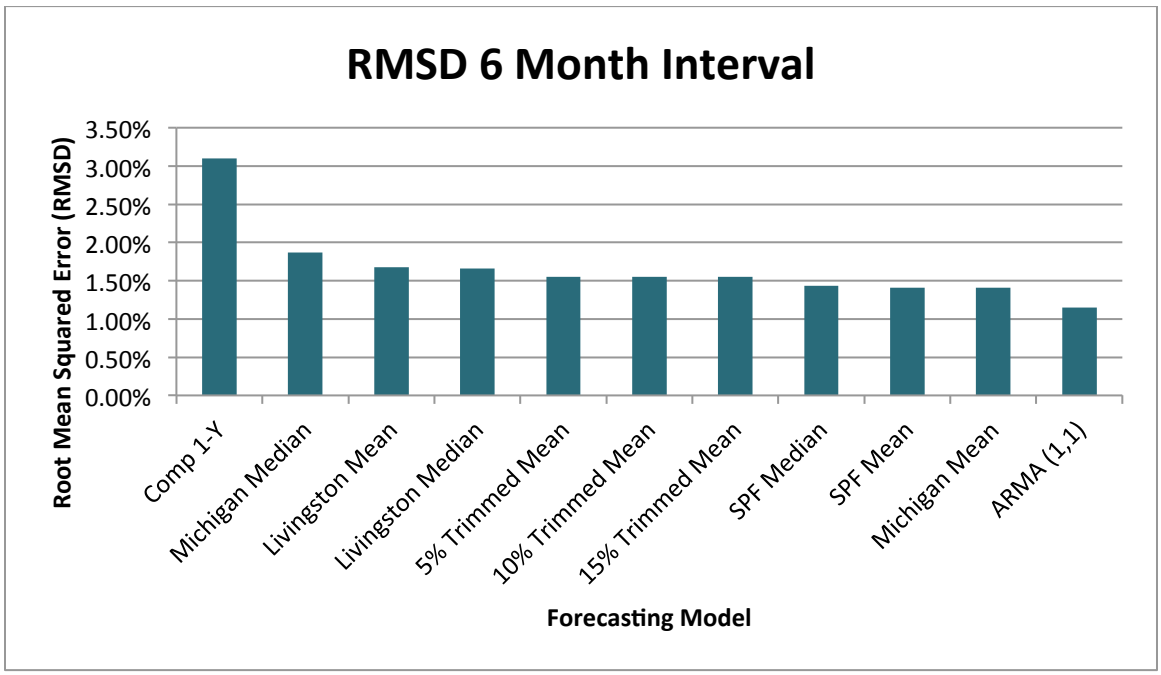

Figure 6.1: 6 Month Root Mean Standard Deviation (RMSD)

Forecasting Model	RMSD
Comp 1-Y	3.10%
Michigan Median	1.87%
Livingston Mean	1.68%
Livingston Median	1.66%
5% Trimmed Mean	1.55%
10% Trimmed Mean	1.55%
15% Trimmed Mean	1.55%
SPF Median	1.44%
SPF Mean	1.41%
Michigan Mean	1.40%
ARMA (1,1)	1.15%

Table 6.1: Summary of the 6 Month RMSD by forecast

3 Months

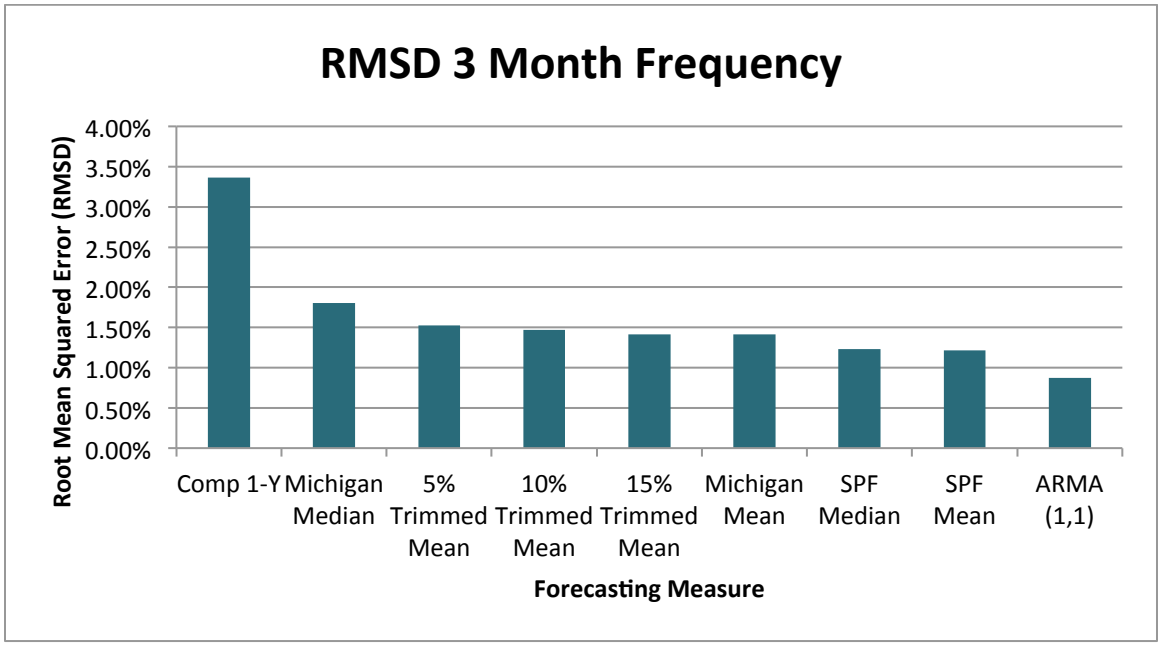

Figure 6.2: 3 Month Root Mean Standard Deviation (RMSD)

Forecasting Model	RMSD
Comp 1-Y	3.36%
Michigan Median	1.80%
5% Trimmed Mean	1.53%
10% Trimmed Mean	1.47%
15% Trimmed Mean	1.42%
Michigan Mean	1.41%
SPF Median	1.23%
SPF Mean	1.22%
ARMA (1,1)	0.87%

Table 6.2: Summary of RMSD by forecast

1 Month

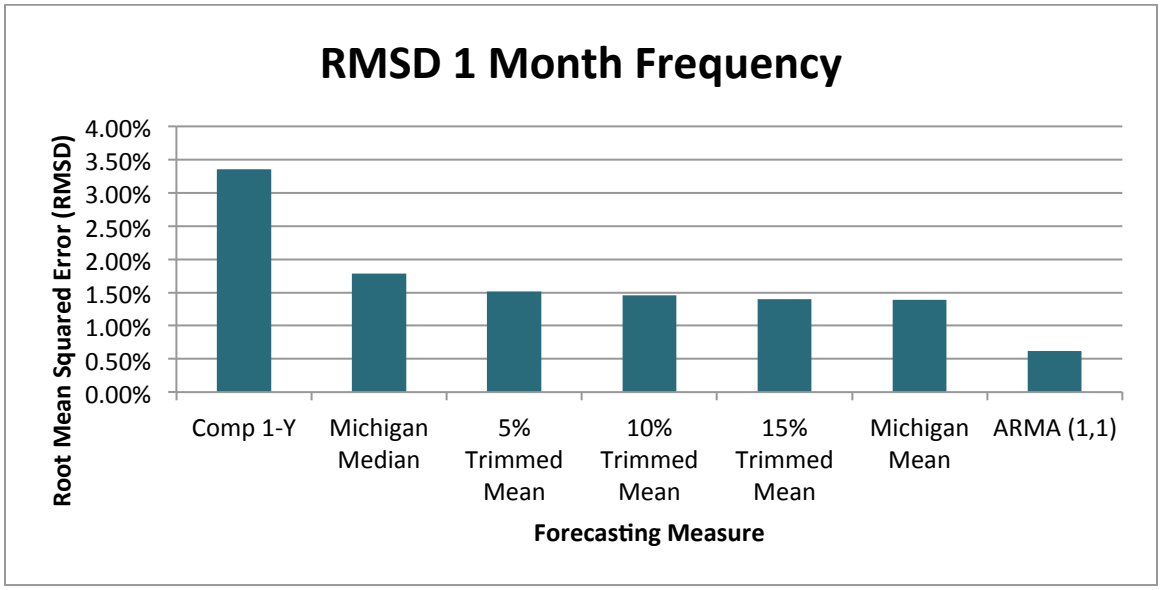

Figure 6.3: 3 Month Root Mean Standard Deviation (RMSD)

Forecasting Model	RMSD
Comp 1-Y	3.35%
Michigan Median	1.78%
5% Trimmed Mean	1.51%
10% Trimmed Mean	1.45%
15% Trimmed Mean	1.40%
Michigan Mean	1.39%
ARMA (1,1)	0.62%

Table 6.3: Summary of RMSD by forecast

Chapter 7

7.1 Analysis of Results

After looking at the results we find that the ARMA (1,1) was the best forecast of CPI-U and that the 1-Year Composite was consistently the worst forecast of CPI-U. There were some major conclusions drawn from the results obtained:

1. Forecasting Accuracy of ARMA (1,1): As confirmed by different studies, we found that the ARMA model has great predictive capabilities. This finding has important repercussions in the way that we think about the value of experts in predicting macroeconomic variables. In other words, it might be possible that Statistical Tests yield more accurate forecasts than experts in a subject matter.

2. The Mean as a better predictor than the Median: Across all surveys we found that the Mean was a more accurate predictor of CPI-U than the Median. This implies that for future studies that use forecasts, the Median forecast is less accurate than the Mean.

3. Arbitrage-Free Model as a bad predictor: The 1-Year Composite was consistently the worst predictor of inflation. This can be attributed to the Liquidity and Inflation Premiums. To illustrate the fact that the 1-Year Composite was very inaccurate mostly because of the lack of predictive ability of Short-Term T-Bills and because of lack of liquidity in the TIIS market refer to the next two figures:

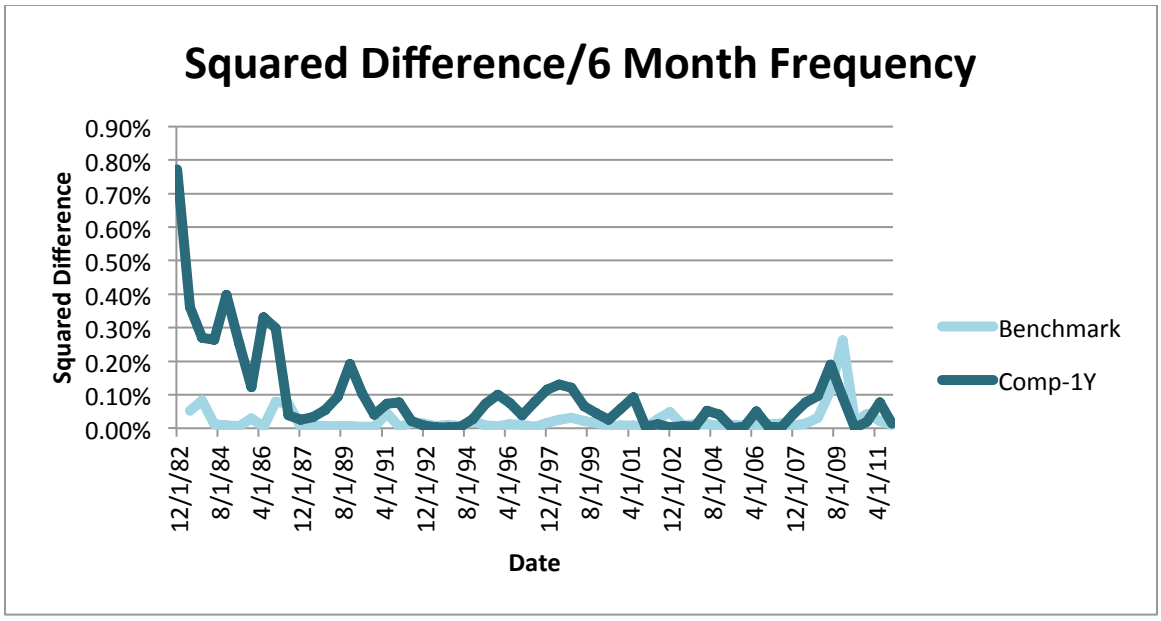

Figure 7.1: Squared Difference/6 Month Frequency since 1982. Benchmark Vs. Comp-1Y

In Figure 7.1 it is clear that before 1999 the Market Expectations of inflation were very inaccurate. During this time period only T-Bill yields were available, therefore we used the T-Bill yields as the closest market predictor of inflation in the 1-Year Composite.

Even though we know that T-Bills were inaccurate forecasters of inflation we want to know if TIIS can become an accurate predictor of inflation. In order to find if TIIS are better inflation predictors we analyzed how the Comp-1Y performed once we only take into account the years after TIIS expectations of inflation substitute the T-Bills in the Comp-1Y (After 2001).

Figure 7.2 clearly shows that when T-Bills are not used to predict inflation, the accuracy of the Market Composite is substantially better! Therefore TIIS can produce substantially better forecasts of inflation than Treasury Bills.

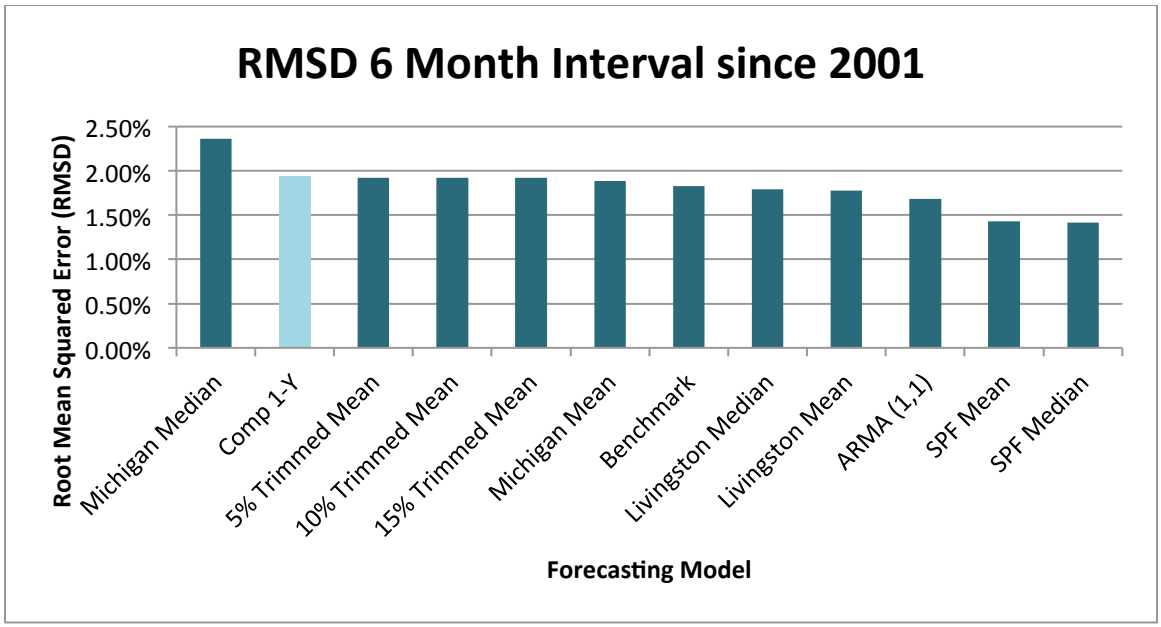

Figure 7.2: RMSD on a 6 Month Frequency starting on June 2001

4. The 15% Trimmed Mean was consistently the best Trimmed-Mean forecast, followed by the 10% and the 5%. This includes the three frequencies and also the period starting in 2001.

5. The Survey of Professional Forecasters (SPF) accuracy after 2001: As shown in Figure 7.2, the SPF has become increasingly better in terms of predicting future inflation. A possible explanation for this result is that SPF incorporates data from statistical methods in addition to macroeconomic factors that statistical analysis cannot incorporate.

Chapter 8

8.1 Relevant Applications

Accurate forecasts of CPI-U could potentially be useful to:

8.1.1 Policy Makers

1. Fiscal Policy: With an accurate prediction of inflation fiscal policy could change in order to avoid price instability (if inflation is expected to be high, government spending should decrease and vice versa).
2. Monetary Policy: One of the dual mandates of the Federal Reserve is to maintain prices stable (inflation between 2% and 3%), therefore accurately predicting inflation is extremely important. Inflation forecasts become even more valuable in recent days since the Federal Reserve's Balance Sheet has grown to become so large that many analysts argue that we might face "runaway" inflation in the upcoming years. Additionally, research could solve the problem of the inaccuracy of using the Taylor Rule to determine monetary policy ("Output Gaps and Monetary Policy at Low Interest Rates" by Roberto M. Billi)

8.1.2 Corporations

1. Inventory levels: Corporations could benefit from changing their inventory levels depending on the forecasted level of inflation
2. NPV decision-making (capital allocation): An accurate forecast of inflation could determine if a projects NPV is positive or negative, driving the capital allocation of the company

8.1.3 Individuals

1. Saving Vs. Spending: Individuals can decide to change their marginal propensity to consume depending on the expected real return on their savings (nominal minus inflation)

8.1.4 Investors

1. Benchmarking: Some institutions are benchmarked against inflation, therefore if they could predict inflation accurately these institutions could potentially optimize returns.
2. Arbitrage: From our results it is clear that currently market expectations of inflation are far from accurate. In fact, it is clear that a simple statistical model such as ARMA (1,1) can predict more accurately than humans can. A possible strategy to profit from this situation is to rely on statistical models and trade accordingly. For example: If the ARMA model is predicting an annualized inflation of 3% for next month and the Arbitrage-Free Model predicts an inflationary level of 1% then it is better to buy TIIS and short a

Nominal Bond that matures at the same date (Alternatively borrow the cost of the TIIS through a broker).

Bottom line, inflation is a very important macroeconomic variable since it converts every measure of production into real terms. According to economic theory we are considered to be "better off" only when we are wealthier in "real terms" (when our nominal return minus inflation is larger than zero). Therefore, realizing what the best forecast of inflation is will allow players in the economy to optimize their "real wealth" and therefore their utility.

Chapter 9

9.1 Conclusions and Further Research Comments

9.1.1 Conclusions

After considering different models to forecast inflation we concluded the following:

1. It does not make a significant difference in the results to compare over different frequencies: The best forecast was consistently ARMA (1,1) over all frequencies and the worst predictor was the 1-Y Market Composite. Even though the frequencies were different the results were the same.

2. It does make a significant difference to compare over different periods: When we compared the 1-Y Market Composite over the years after 2001 there was a significant difference in terms of the results obtained. The 1-Y Market Composite was no longer the worst predictor of Inflation. Instead it was the Michigan Median.

3. Statistical Forecasts can actually produce better predictions than experts consistently: ARMA (1,1) was consistently the best predictor of inflation. Additionally the 15% Trimmed-Mean was also very robust at predicting inflation.

9.1.2 Further Research Comments

Further research needs to be implemented in the following areas:

1. Increasing sample size for Arbitrage-Free Model forecasts. Currently we only have a few observations since 2001, therefore measuring forecasting accuracy for only 11 years can be misleading. Adding additional years will allow market participants to gage the predictive capabilities of Arbitrage-Free Models made with TIIS.

2. Measuring Liquidity and Inflation Premiums would present investors with a clear view of what is the actual market-expected inflation rate. Currently there is no definite solution on this matter. A possible strategy to tackle this problem would be to create a government sponsored instrument that would trade these premiums.

3. Using more sophisticated statistical forecasting models and compare to basic models such as ARMA (1,1). This could potentially shed more light on the level of complexity necessary to optimize the predictive power of statistical models in general.

4. Measure the predictive capabilities of different forecasts of CPI-U for the next 2, 5, 10, 15 and 20 years. Currently most studies focus on forecasts that predict inflation for the next year, but it is possible that forecasts for longer periods of time are more reliable.

5. Further research could also look at other countries that have also issued similar securities such as Canada, U.K., Australia, Sweden and New Zealand

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- Smeal Trading Strategy Competition
- Traders Trophy International Competition
- Penn State Investment Association Stock Pitch
- DANONE Trust Case
- PwC xACT Case
- Kohl's Case

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