TIPS ETF: An Explanatory Model using CPI

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Abstract

This paper investigates the relationship between ETFs composed of Treasury Inflation Protected Securities (TIPS) and inflation as indicated by the CPI. The iShares TIPS ETF and the Consumer Price Index for All Urban Consumers (CPIAUCSL) metric are selected for analysis. Our main result is to establish the rationale which governs the behavior of participants in this market. Strong upwards or strong downwards movements of inflation, or the absence of either, are the major factors governing participants' behavior. This insight leads to the identification of three distinct regimes of TIPS ETF price movements during varying types of shocks in the CPIAUCSL. A model is then constructed using insights from the three regimes. The model is tested by out of sample data and provides an excellent agreement with observations. An R-squared value of 0.989 is achieved when the model is trained on the first half of the data. The data and the model both suggest an inverse relationship between iShares TIPS ETF price data and the CPIAUCSL metric during strong price shocks.

Keywords: TIPS ETF, CPI, iShares, TIPS, CPIAUCSL, Inflation

1. Introduction

The U.S Federal Reserve has printed more than 6.7 trillion dollars in the last 18 months, which is roughly equivalent to 40% of all U. S currency. With this statistic alone, high rates of inflation can be expected. Currently, many investors and consumers are turning to inflation protected securities such as TIPS for refuge.

TIPS function like ordinary bonds with the exception that their par value is adjusted with inflation as given by the Consumer Price Index. As the par value is adjusted, the interest payments are made based on the new principal. At the time of maturity, the buyer is paid back either the original or current par value — whichever is greater. TIPS have lower and usually significantly lower yields as compared to Treasury notes and bills of comparable maturities. Customers are motivated to buy TIPS only when inflation is expected to be high during the life of the bond.

Due to their unique characteristics, TIPS have been assessed for their viability as a low-risk, liquid, and protective instrument against inflation. ETFs provide an alternative vehicle to investment in TIPS. The major advantages are ease of purchase and higher liquidity. The previously identified motivational factors governing the price movements of TIPS apply to the TIPS ETF as well.

The purpose of this paper is to examine

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quantitatively the price behavior of TIPS ETFs in association with the CPIAUCSL metric. With this study we derive statistical relations between price movements of TIPS ETF and the buyers' reactions to inflation. Our analysis establishes statistically CPIAUCSL as a signal for trends in TIPS ETF price. This information is useful to investors and firms with significant holdings in TIPS ETFs.

1.1. Summary of Results

The time-series of the Consumer Price Index for All Urban Consumers (CPIAUCSL) and the iShares TIPS ETF are analyzed to reveal three distinct regimes of TIPS ETF price behavior during various types of shocks to the CPI metric. During weak shocks to the CPIAUCSL, the iShares TIPS ETF sees no change in behavior. During strong upward shocks to CPIAUCSL, the iShares TIPS ETF skews slightly higher than expectation. During the strong downward shocks to CPIAUCSL, the iShares TIPS ETF price trends over its expectation by the largest magnitude. These observations are incorporated into an explanatory model that relates the key motivational factors observed in the CPIAUCSL to the iShares TIPS ETF price. The model is tested for consistency with out of sample testing and is observed to be consistent with the data.

1.2. Basic Definitions

A Treasury Inflation-Protected Security (TIPS) is a Treasury bond whose principal is indexed to the Consumer Price Index (CPI). It functions like an ordinary bond and pays semi-annual coupon payments. However, the principal of the bond is adjusted at the end of each year according to the increase or decrease in inflation. Any coupon payments made the next year are then calculated off the new principal. At the time of maturity, the purchaser is paid the greater of the par value and the current face value.

The Consumer Price Index for All Urban Consumer: Weighted Average (CPIAUCSL) is a metric provided by the Federal Reserve of Economic Data (FRED) that measures the weighted average of baskets of goods and services found in thousands of urban locations across the U.S. More information regarding this metric is provided in Section 3.

The iShares TIPS ETF is an exchange traded fund composed entirely of TIPS. It is one of many TIPS ETFs on the market. It is one of the most popular and diverse in its category.

1.3. Prior Study on TIPS ETFs and CPI

We have identified a few prior studies that discuss the viability of TIPS ETF as long-term investments and the general relationship between the CPI and TIPS. Ref. [6] observed that TIPS were under priced compared to ordinary Treasury bonds in the years after 2000. It backs this statement by explaining the different motivations TIPS buyers have versus Treasury bond buyers and compares the liquidity and trust of both assets. Ref. [7] cites statistics that show investors increasingly underforecast inflation. They decrease the yield premium on the TIPS and increase the price of existing TIPS and TIPS ETF. The years leading up to 2007 show a consistent underestimation of inflation at TIPS auctions. As a result, TIPS returns increased as well up to 2007. Importantly, Ref. [7] also gives a contextual explanation for the inverse relationship that is further explored in the present paper. It cites that inflation concerned investors may have a "bias towards the status quo." Concretely, they underestimate inflation when current inflationary pressures are high, and overestimate inflation when current inflationary pressures are low. Since Ref. [7] shows this underestimation leads to higher TIPS prices and thus higher TIPS ETF prices, while high inflationary pressures prompted policy changes which decreased inflation, an inverse relationship with a significant time delay can be seen. Inflation concern is studied in [2] which links macroeconomic changes, e.g. Coronavirus related to a strong movement of investors into the TIPS sector. These investors were looking for speculative returns and inflation protection. Also, [1] cites real wealth as the "appropriate focus" of individual portfolios consisting of TIPS.

2. Justification for Selecting iShares TIPS ETF

As fears of inflation have grown, large numbers of investors have purchased TIPS ETFs. According to [2], every single ETF with the word "inflation" in its name or description has recorded large inflows in 2020 and 2021. More than $35.5 billion was placed in these ETFs, making their growth rate three times higher than the ETF industry overall. A key fact to note is that individual investors are making up a large portion of these TIPS ETFs. According to [4], "the inflows into the TIPS sector are coming from individual investors, financial advisers on behalf of clients, institutional investors." Also, according to Fidelity and BlackRock, it is estimated that individuals own about 40% of the outstanding shares of the iShares TIPS ETF.

Given that a large fraction of actively circulating shares in the iShares TIPS ETF are owned by individual investors, we hypothesize that its price behavior will best reflect the sentiment of the general populous regarding inflation. Concretely, the iShares TIPS ETF is ideal for analysis as it would likely be the first stop for inflation concerned investors and thus would best indicate the broad population's outlook on inflation. Lastly, the iShares TIPS ETF contains a good diversity of TIPS maturities, ensuring that the composition of the ETF remains stable as certain TIPS in the ETF mature.

3. Justification for Selecting CPIAUCSL Metric

The Consumer Price Index for All Urban Consumers: All Items (CPIAUCSL) is the best metric to reflect inflation in urban areas. According to the Federal Reserve Economic Data (FRED), it measures the "average monthly change in price for goods and services paid by urban consumers." The prices are collected from 4,000 housing units and 26,000 retail establishments across 87 urban areas. Additionally, the index covers roughly 88% of the total population, and "accounts for wage earners, clerical workers, technical workers, self-employed, short-term workers, unemployed, retirees, and those not in the labor force" (FRED).

The statistics above show that the metric gives a very clear picture of inflation in the goods purchased by the average urban consumer, covering a vast majority of the wage earning population and a broad range of employment types. A key assumption is now made that urban consumers/earners are the most likely individual investor demographic to have knowledge of and thus purchase TIPS ETFs. Following this assumption, it is logical to study how the CPIAUCSL would spark sentiments about inflation in urban consumers/earners, leading to the purchase of TIPS ETFs. Hence, the rationale for selecting the CPIAUCSL metric for analysis becomes relatively simple: it is the metric whose changes are most visible in everyday activities for urban consumers and would most likely lead them into purchasing/selling TIPS ETFs. As a result, the CPIAUCSL becomes a prime target for comparison with TIPS ETFs.

4. Historical Context of iShares TIPS ETF & CPIAUCSL

Before beginning our analysis, we examine long-term trends in the time-series of both the CPIAUCSL and the iShares TIPS ETF. Fig. 1 displays the TIPS iShares ETF time-series.

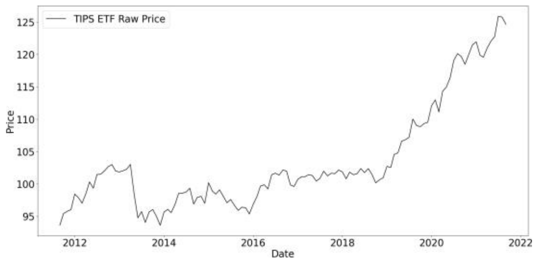

Figure 1: **10-year Historical Price of iShares TIPS ETF**

The trend is roughly flat until 2019, where it begins a steady climb higher. Until 2019, the TIPS variation is fixed between 95 and 105 dollars. In 2019, it breaks out from this range and climbs steeply but steadily till the end of the graph. This is expected given the prior discussion on the increased inflow of cash into TIPS ETF since 2019. Notable down turns are seen at the end of 2013 and the beginning of 2020. The downturn in 2013 coincides with the debt ceiling crisis that the U.S government faced that year during which deliberations were held on the limit of government spending and minting. Hence, it is not unexpected to see fluctuations in an inflation themed ETF. The downturn in 2020 coincides with the general economic downturn the U.S faced that year. Overall, this is a non-stationary time series with values that range from 95 to 130.

Next, we discuss the 10-year history of the CPIAUCSL. The CPIAUCSL has trended upwards in its entire 10-year history, with no significant periods of draw down. As expected, this implies a steady growth of inflation each year in urban areas. Two small downturns occur in 2015 and the beginning of 2020. The down turn in 2015 may be explained by the small recession affecting import prices that year. The same explanation may be given for the downturn in 2020. Overall, it is a non-stationary time-series with a seemingly constant variance.

5. Justification for Utilizing Primitive Statistical Procedures

Before analysis and processing, we review the logistics of the data being used. For both the iShares TIPS ETF and the CPIAUCSL, we are using monthly data from 9/1/2011 to 9/1/2021. The iShares TIPS ETF time-series is cleaned and adjusted for values corresponding to weekends when the ETF is not traded. The CPIAUCSL data is provided by FRED Economic Research and is cleaned and seasonally adjusted. The iShares TIPS ETF data is provided by Yahoo Finance API.

Given that the data is at a monthly frequency and has a history of 10 years, the total data points for each time-series is 120. Traditional financial data analysis techniques are not applicable for such a short time series. We identify primitive methods of statistical analysis that give insight into the nature of the time-series.

6. Extreme Values & Moving Average

We begin analysis by reviewing our goal of investigating the influence of the CPIAUCSL may on the iShares TIPS ETF. Logically, the best place to look for any such relationship would be at the extremes of each time series. For example, TIPS ETF buyers would most likely be influenced by the sharpest increases and decreases in inflation rather than the moderate ones. Looking at Fig. 1 and the discussion in Sec. 4, we see that both time-series are non-stationary. Furthermore, the log returns of both series are non-stationary. Hence, we cannot look for extreme values since both time-series trend upwards throughout their history and thus all later values in time-series are extreme compared to the earlier values. To avoid this difficulty, we create a simple moving average to use as a comparison basis. We find minima and maxima relative to the moving average. This is done by calculating the mean of the three previous monthly values in the time-series.

$$3 - month\ SMA = \sum_{i=1}^{3} X_{k-i}/3 \qquad (1)$$

$$X_k = K^{th}\ datapoint$$

Fig. 2 shows a comparison of the simple moving average to the raw data for iShares TIPS ETF. The same analysis is applied CPIAUCSL time series.

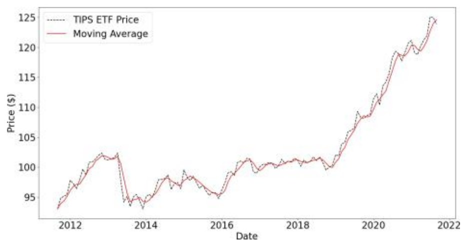

Figure 2: **3-Month SMA vs Raw Price for iShares TIPS ETF**

We can see that the 3-month simple moving average roughly follows the original time series but deviates when there are sharp rises or drops. We follow the same process for the CPIAUCSL time-series.

7. Moving Average Deviations

Now that we have calculated the moving averages for both time-series, we have a comparison basis to find extreme values. For example, if the iShares TIPS ETF price is significantly higher than the moving average for that month, then it is an extreme value. In other words, a value substantially higher/lower than its 3-month expectation is declared to be an extreme value. To expand on this idea, we calculate the deviations of each value in the time-series from its 3-month moving average. We do that by simply subtracting the moving average of a time series at a certain month from the raw value at that same month. Using Fig. 2 as an example, we find the differences between the solid black curve and the dashed red curve. The deviation is given in Eq. 2 with SMA representing the simple moving average data point.

$$Deviation\ (X_i) = X_i - SMA\ (X_i) \qquad (2)$$

Eq. 2 defines a new time-series which measures the extent to which each point in the original time series deviates from the moving-average of that month. If the value is positive, it means that the price/value in that month is higher than expected based on the 3-month moving average. If it is negative, it means that the price/value is lower than expected based on the 3-month moving average. The deviations for both the iShares TIPS ETF and the CPIAUCSL are given in Fig. 3.

In Fig. 3, it is difficult to discern a pattern in the relation between the fluctuations of the iShares TIPS ETF and CPIAUCSL relative to their moving averages. To overcome this effect, we refine Fig. 3 to include only the strongest deviations in each time-series. Our approach is to calculate the percentile ranking of each deviation for both time-series and pick the deviations with the largest percentiles.

Since the deviations are both positive and negative, we need to find the percentile ranking of each deviation by their absolute magnitude. We place the absolute values in an ordered list and then calculate the percentile. As the distribution of deviations

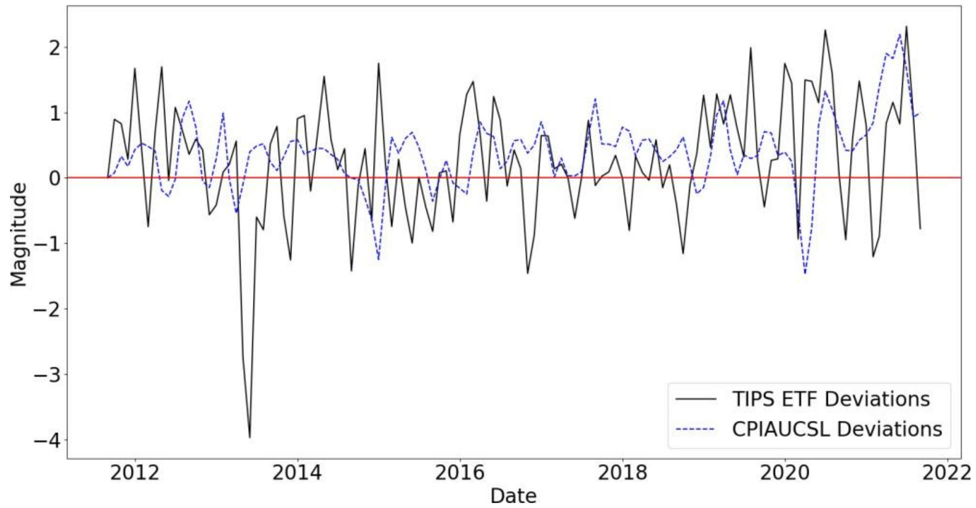

Figure 3: **Historical Moving Average Deviations for iShares TIPS ETF & CPIAUCSL**

for iShares TIPS ETF and CPIAUCSL are both heavy tailed, the percentile is computed using software. After this is done, we can plot Fig. 3 again, this time only including the largest 15 percent of all deviations. This filters out most of the noise coming from the smaller deviations and give a clearer picture of the response on one time series to an extreme value in the other. The graph is seen in Fig. 4.

Now that only the strongest deviations are being considered, we see an inverse relationship between the iShares TIPS ETF price and the CPIAUCSL value. Most notably, whenever there are strong decreases in the CPIAUCSL, the TIPS ETF rise sharply over its moving average. Additionally, when the CPIAUCSL starts to rise over its moving average, there is downward pressure on the TIPS ETF price. These inverse relationships are highlighted in Fig. 4.

As seen in the highlighted regions, the TIPS ETF and CPIAUCSL follow an inverse relationship whenever there are strong shocks to either time series. Only a small portion of the graph breaks away from the inverse relationship, as is seen between indexes 12 and 15 in Fig. 4. However, even in that region, the CPIAUCSL is trending over its 3-month expectation, and inversely the iShares TIPS ETF is under its moving average.

This idea is expanded by investigating the distribution of the TIPS ETF moving average deviations when the CPIAUCSL trends (a) strongly over its expectation (b) strongly under its expectation and (c) near its expectation. Doing so identifies three quantitatively different regimes for the construction of a model that relates the two time series. Finally, weak CPIAUCSL deviations are defined as a magnitude less than 30th percentile.

Plotting the three distributions as box plots gives a visual picture of the way TIPS ETF deviates when CPIAUCSL trends strongly over or under its expectation. Before we do so however, we remove any far outliers that may warp the box plots. The graph is shown in Fig. 5.

The box plots in Fig. 5 show 3 distinct regimes of TIPS ETF deviations. The left box plot shows the TIPS ETF deviating relatively little during weak shocks to CPIAUCSL. The middle box plot shows

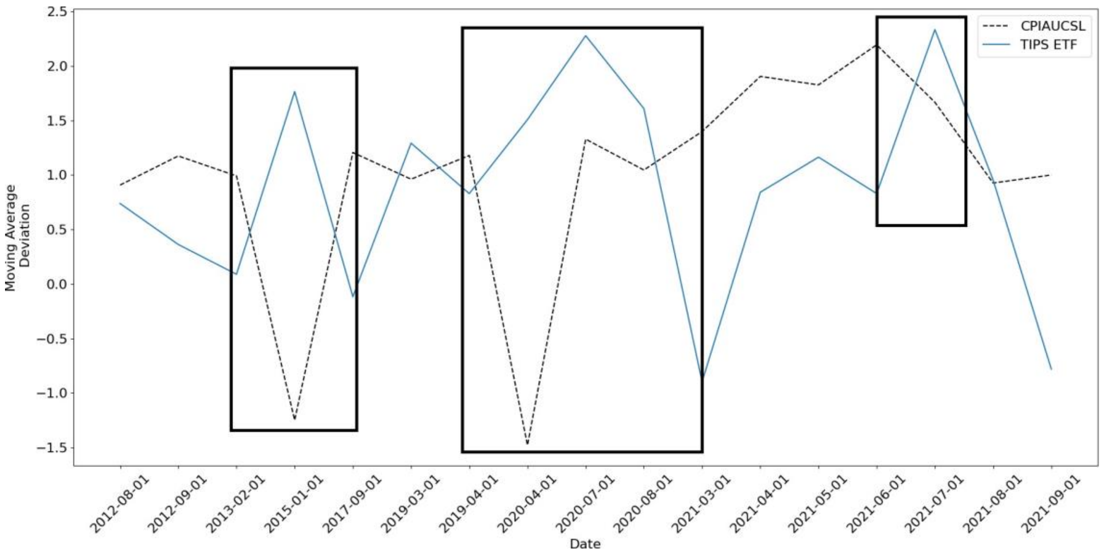

Figure 4: **85th Percentile Historical Moving Average Deviations**

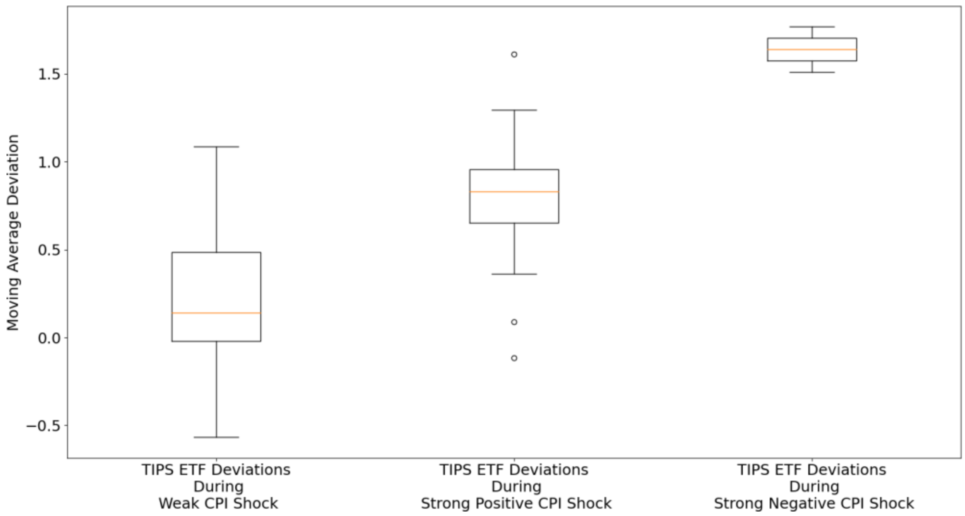

Figure 5: **iShares TIPS ETF Moving Average Deviations Sorted by CPI Shock Strength**

higher TIPS ETF deviations during strong upwards shocks to CPIAUCSL. It distinctly separates from the leftmost box plot. The right box plot importantly shows that when the CPIAUCSL has strong downward shocks and trends under its 3-month expectation, the iShares TIPS ETF increases over almost all the other deviations in its 10-year history. This is seen as the third box plot is almost entirely over the two other box plots. This is key as it shows that when the CPIAUCSL has strongly trended under its moving average, the TIPS ETF trends over its moving average at a level higher than almost all other cases in its history. With this result, we ask whether seeing extremely low inflation rates — as indicated by the CPIAUCSL — may signal a peak in TIPS ETF performances.

Additionally, when the CPIAUCSL has upward shocks over its expectation, the range of TIPS ETF deviations also tend to skew positively. Although the pattern is not as clear as the box plot when CPIAUCSL has downward shocks, it still defines a regime. When considering Fig. 5 as a whole, it concretely shows that the largest increases in TIPS ETF price occur during large downturns in CPIAUCSL. This observation is key to any potential investors in iShares TIPS ETF.

8. Statistical Significance

We asses the statistical significance of the trends identified in Sec. 6 and 7. We confirm that the distribution of the three regimes in Fig. 5 are statistically different. To test whether two distributions are different from one another, we use the 2-sample Kolmogorov-Smirnov test. This test is run pairwise on the three possible pairs. The resulting p-values are presented tabulated schematically in Fig. 6. A low p-value indicates that the two distributions are statistically significantly distinct from each other. The diagonal is left blank as it is comparing a distribution to itself.

As seen from Fig. 6, the distribution of the iShares TIPS ETF deviations when CPIAUCSL is under its expectation statistically significantly differs from all other circumstances, with a p-value of 0.005. This fact states that the iShares TIPS ETF behaves significantly different from its norm when the CPIAUCSL is lower than expected. This gives statis- tical support to the earlier hypothesis of an inverse relation between TIPS ETF and the CPI metric. Additionally, we see that the TIPS ETF deviation distribution during weak CPIAUCSL shocks is statistically different from both other distributions. This implies that the iShares TIPS ETF very likely may be significantly influenced by larger shocks to the CPIAUCSL as compared to weaker shocks. We also see that the distribution of TIPS ETF deviations during upward shocks to CPIAUCSL is qualitatively distinct from the distribution concerning downward shocks to CPIAUCSL. The p-value, while not sufficient to reject the null hypothesis, does suggest a significant difference. This can be explained as downward shocks in inflation expectations incite a decrease in motivation to hold TIPS ETF and a decrease in the rate premium that TIPS holders will allow. As with most investments, the investor is skewed, with a larger response to losses (panics, etc.) than the investment response to good news (positive shocks for inflation) and inflation tending higher. For this reason, the negative shocks are most dramatically different from the other two and the high inflation extremes (good news for TIPS holders) is weakly differentiated from the negative shocks. This analysis of investor psychology is a key point that builds the foundation of the reciprocal relationship discussed in earlier sections.

9. Modeling iShares TIPS ETF

Using the observations from the previous sections, we construct an explanatory model for iShares TIPS ETF price. It uses the present-day TIPS ETF moving average, along with the present-day CPIAUCSL deviation and other terms, to estimate present-day TIPS ETF price. Our starting point is a model that incorporates auto-regressive terms and terms dependent on the CPIAUCSL. The auto-regressive terms form a good hypothesis during ordinary movement in the TIPS ETF and the CPIAUCSL terms account for behavior during extreme fluctuations as seen in Fig. 4. We choose a simple linear com- bination of the two terms described above. The parametrization of the model has to reflect the three identified regimes to capture the variation in the time-series. Given that the regime created by considering down-

	TIPS ETF Deviations During Weak Shocks to CPIAUCSL	TIPS ETF Deviations During Strong Positive Shocks to CPIAUCSL	TIPS ETF Deviations During Strong Negative Shocks to CPIAUCSL
TIPS ETF Deviations During Weak Shocks to CPIAUCSL		p = 0.006	P = 0.005
TIPS ETF Deviations During Strong Positive Shocks to CPIAUCSL	P = 0.006		P = 0.057
TIPS ETF Deviations During Strong Negative Shocks to CPIAUCSL	P = 0.005	P = 0.057	

Figure 6: Visual Representation of 2-sample KS Test Results

ward CPIAUCSL shocks was the most statistically distinct in the group, a separate set of parameters will be assigned to it in the model. Since the regimes associated with weak and positive CPIAUCSL deviations were not as separate from each other, they share the same set of parameters in the model. Finally, during strong downward deviations in TIPS ETF, another separate set of parameters will be assigned so that downturns unrelated to CPIAUCSL can be accounted for. Keeping these considerations in mind, a model skeleton can be formed which outlines three distinct scenarios. The relation of the model to the three parameter choices is shown in Fig. 7. As seen in Fig. 7, a linear combination of unique parameters can be trained for each of three situations. This gives the model flexibility to account for the variance in the time-series.

Next, the model is trained on the first 5 years of data and is then tested on the remaining 5 years. The least-squares cost function used for training the parameters.

The cost function is minimized for each of the three scenarios outlined in Fig7. An intercept term is also added to increase the leverage of the model. Finally, the model is plotted along with the actual values.

The model in Fig. 8 closely matches the actual time-series, even during sharp movements. The sum of squares error is 81 and the R-squared value is 0.989 when assessed on all 10 years. The model is consistent with the data and confirms motivational factors discussed earlier. This is valuable because an investor can identify extreme CPI values by referencing historically extreme deviations and assess risk in iShares TIPS ETF by using the motivational factors confirmed by the model.

10. Conclusion

We have isolated decision factors which drive price behavior in the iShares TIPS ETF, as responses to unusually strong changes in inflation as indicated by the CPIAUCSL. Three regimes of iShares TIPS ETF price behavior were identified as responses to CPIAUCSL: one regime during weak shocks to CPIAUCSL, another regime during strong upward shocks to CPIAUCSL, and the last regime during strong downward shocks to CPIAUCSL. It was noted that the iShares TIPS ETF had the largest increase over its expectation during strong downward movements in CPIAUCSL. This is valuable to investors as it suggests that sudden drops in inflation signal a peak in iShares TIPS ETF price.

If CPI Deviated Downward Strongly:

TIPS ETF(t) = TIPS Moving Average(t) + B1*CPI Deviation(t) + B2*TIPS Deviation(t – 1) + B3

If TIPS Deviated Downward Strongly:

TIPS ETF(t) = TIPS Moving Average(t) + B4*CPI Deviation(t) + B5*TIPS Deviation(t – 1) + B6

In all other cases:

TIPS ETF(t) = TIPS Moving Average(t) + B7*CPI Deviation(t) + B8*TIPS Deviation(t – 1) + B9

Figure 7: Model architecture Using auto-regressive & CPIAUCSL terms

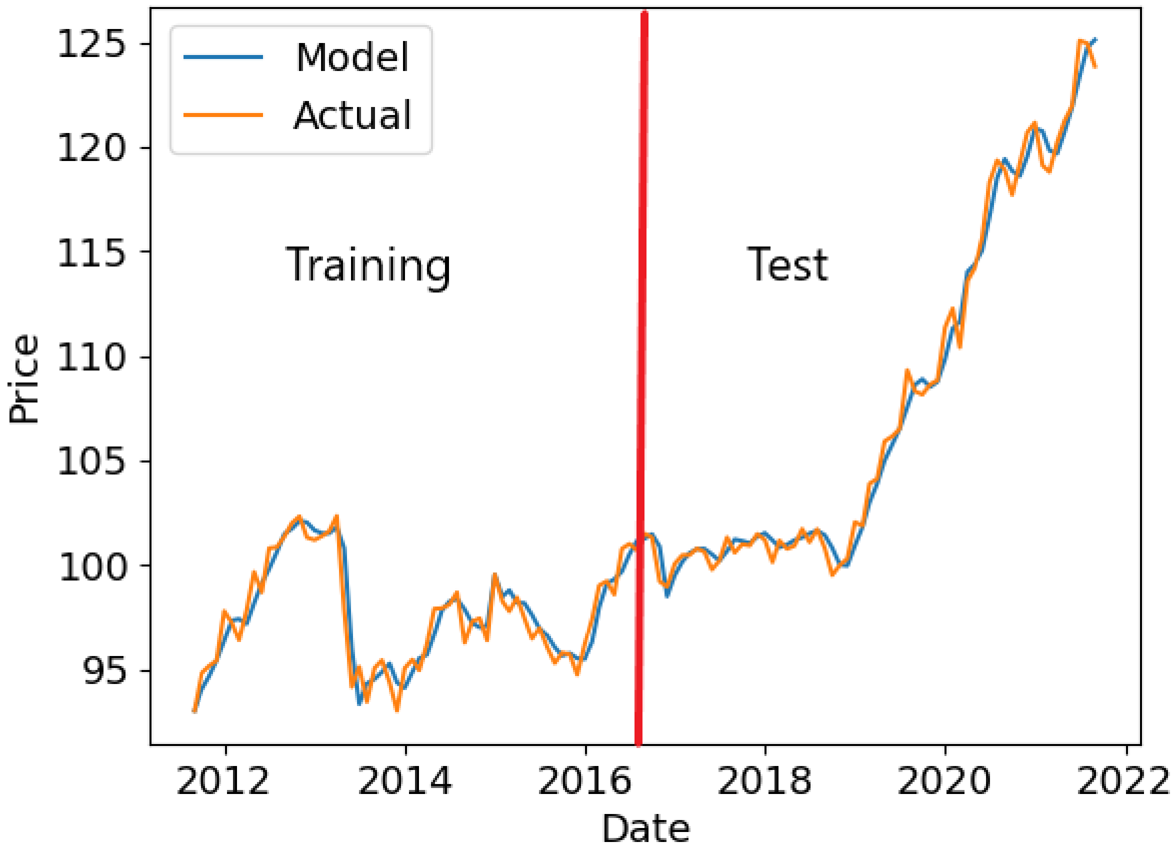

Figure 8: iShares TIPS ETF Model versus Actual

We tested whether the three regimes were statistically different using a two parameter Kolmogorov-Smirnov test. Two of the three pairwise comparisons are shown to be distinct by the KS metric. The third marginally allowing the null hypothesis of no distinction, is in fact distinct but not strongly distinct. We built a model for iShares TIPS ETF based on these observations. The model had three sets of parameters for each of three regimes: a regime considering strong downward shocks to CPIAUCSL, a regime considering strong upward shocks as well as weak shocks to CPIACUSL, and a regime considering strong downturns in the iShares TIPS ETF itself. The model, with in sample testing, showed excellent agreement between the signals and the observed price signals in the iShares TIPS ETF.

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