Fixed Income Securities

Project Report

Spring 2018

The TIPS – Treasury Bond Puzzle

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1. Introduction

The Treasury bonds and the Treasury Inflation-Protected Securities (TIPS) markets are two of the largest and most actively traded fixed-income markets in the world. Treasury inflation-protected securities (TIPS) are inflation-indexed debt securities issued by the U.S. Treasury and marketed as providing protection against inflation. Their principal amount is adjusted for inflation: it increases with inflation and decreases with deflation. They were first auctioned in January 1997 after the market expressed a strong interest in the inflation-indexed asset class. Fig. 1 shows the monthly volume of TIPS growth from 2001-2018.

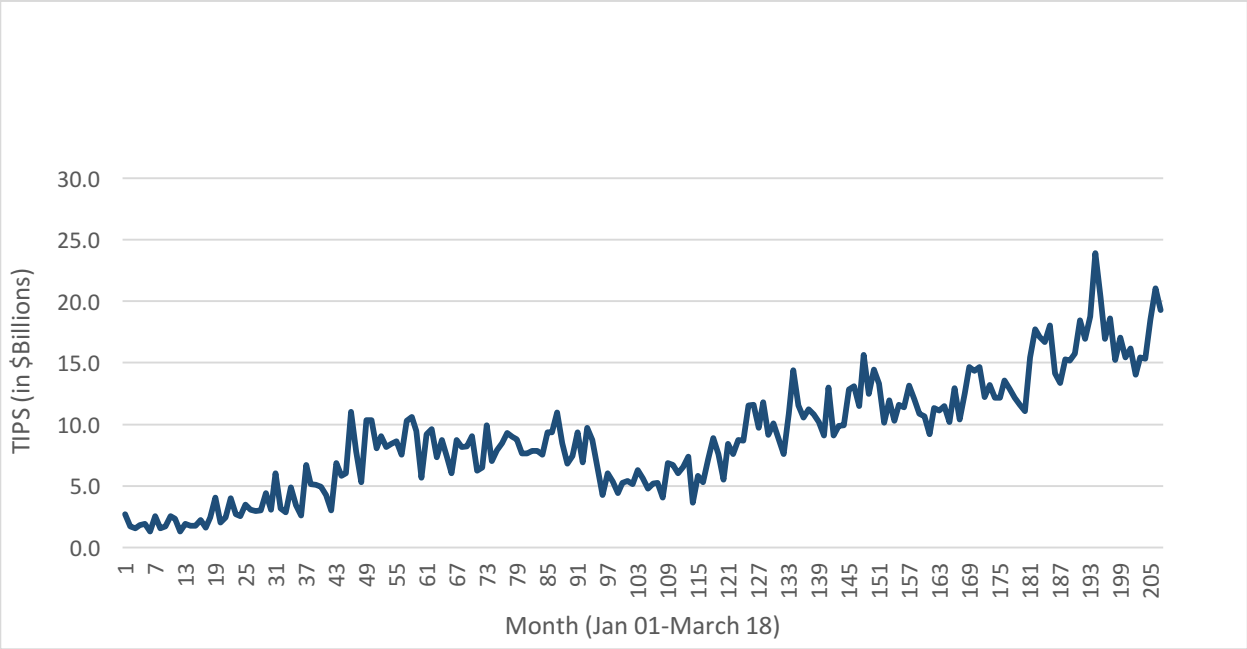


Figure 1: Volume of Monthly TIPS Growth

A notable observation is that there exists a persistent mispricing on a massive scale across the TIPS and Treasury bond markets. Furthermore, this mispricing is almost invariably in one direction—Treasury bonds are consistently overpriced relative to TIPS. The relative mispricing of TIPS and Treasury bonds represents one of the largest examples of arbitrage documented and poses a major puzzle to classical asset pricing theory.

Our project was to replicate the mispricing of TIPS-Treasury Bonds presented in the paper. In addition to this, we extended our analysis to the post-recession period of 2009-2017 to check if the mispricing persisted. The purpose of this is to examine if mispricing was impacted by the crisis of 2008-09.

After performing our analysis, we investigated further whether the U.S. Treasury should continue issuing TIPS along with bonds.

2. Objective

The main objective of this project is to reflect on the effectiveness of issuing TIPS by the U.S. Treasury. The mispricing observed shows that TIPS are underpriced, hence, we checked if this implies that the Treasury is losing money by issuing TIPS.

3. TIPS Treasury Arbitrage

TIPS are direct obligations of the U.S. Treasury and are similar to Treasury bonds in most respects. The key difference is that the principal amount of a TIPS issue is adjusted over time to reflect changes in the Consumer Price Index (CPI). Since the fixed coupon rate for the TIPS issue is applied to its principal amount, the actual semiannual coupon received varies over time as the principal amount changes in response to the realized inflation or deflation rate. Similarly, the final principal amount paid to the bondholder equals the maximum of the original principal amount or the inflation-adjusted principal amount. Thus, TIPS investors' principal is protected against deflation (although the same is not true for coupon payments).

The inflation-linked cash flows from a TIPS issue can be converted into fixed cash flows using inflation swaps. The resulting cash flows can be structured to match exactly those from a Treasury bond with the same maturity date as the TIPS issue. We therefore create a synthetic nominal Treasury bond from the TIPS issue. Price differences between the synthetic Treasury bonds and the nominal Treasury bonds represent straightforward arbitrage opportunities.

4. Replicating and Extending the Arbitrage

4.1 Methodology

Inflation swaps are quoted in terms of the constant rate on the contract's fixed leg. The discount factors and the swap rate which we find from the Bloomberg are for the limited maturity. To find the respective rates for the maturities in between, we have used cubic spline interpolation technique using a python code. To eliminate the mispricing between Tips and Treasury, we replicated the cash flows from the Treasury bond exactly from a TIPS position.

4.2 Replicating Cash flow

The arbitrageur purchases a TIPS issue with a coupon rate of 's' with the same maturity date as the Treasury bond. The TIPS bond pays coupons of $s * I_t$ each period, where I_t is inflation adjustment, and makes a principal payment of 100*I_t at maturity.

The arbitrageur then enters an inflation swap for each coupon payment date with a notional amount of 's' (or 's' + 100 for the final principal payment date). This converts all the indexed cash flows from the TIPS into fixed cash flows. However, to match exactly the cash flows from the Treasury bond, the arbitrageur also needs to long or short a small amount of Treasury STRIPS (separate trading of registered interest and principal securities) for each coupon payment date.

Date	Treasury	TIPS	Inflation Swaps	STRIPS	Total
0	−169.4793	−101.2249	0	−45.6367	−146.3786
1	3.8125	1.1875 I_1	1.1856 − 1.1875 I_1	2.6269	3.8125
2	3.8125	1.1875 I_2	1.1638 − 1.1875 I_2	2.6487	3.8125
3	3.8125	1.1875 I_3	1.1480 − 1.1875 I_3	2.6645	3.8125
4	3.8125	1.1875 I_4	1.1467 − 1.1875 I_4	2.6658	3.8125
5	3.8125	1.1875 I_5	1.1307 − 1.1875 I_5	2.6818	3.8125
6	3.8125	1.1875 I_6	1.1376 − 1.1875 I_6	2.6749	3.8125
7	3.8125	1.1875 I_7	1.1566 − 1.1875 I_7	2.6559	3.8125
8	3.8125	1.1875 I_8	1.1616 − 1.1875 I_8	2.6509	3.8125
9	3.8125	1.1875 I_9	1.1630 − 1.1875 I_9	2.6495	3.8125
10	3.8125	1.1875 I_{10}	1.1773 − 1.1875 I_{10}	2.6352	3.8125
11	3.8125	1.1875 I_{11}	1.1967 − 1.1875 I_{11}	2.6158	3.8125
12	3.8125	1.1875 I_{12}	1.2095 − 1.1875 I_{12}	2.6030	3.8125
13	3.8125	1.1875 I_{13}	1.2248 − 1.1875 I_{13}	2.5877	3.8125
14	3.8125	1.1875 I_{14}	1.2466 − 1.1875 I_{14}	2.5659	3.8125
15	3.8125	1.1875 I_{15}	1.2683 − 1.1875 I_{15}	2.5442	3.8125
16	3.8125	1.1875 I_{16}	1.2866 − 1.1875 I_{16}	2.5259	3.8125
17	3.8125	1.1875 I_{17}	1.3058 − 1.1875 I_{17}	2.5067	3.8125
18	3.8125	1.1875 I_{18}	1.3304 − 1.1875 I_{18}	2.4821	3.8125
19	3.8125	1.1875 I_{19}	1.3556 − 1.1875 I_{19}	2.4569	3.8125
20	3.8125	1.1875 I_{20}	1.3792 − 1.1875 I_{20}	2.4333	3.8125
21	3.8125	1.1875 I_{21}	1.4009 − 1.1875 I_{21}	2.4116	3.8125
22	3.8125	1.1875 I_{22}	1.4225 − 1.1875 I_{22}	2.3900	3.8125
23	3.8125	1.1875 I_{23}	1.4427 − 1.1875 I_{23}	2.3698	3.8125
24	3.8125	1.1875 I_{24}	1.4635 − 1.1875 I_{24}	2.3490	3.8125
25	3.8125	1.1875 I_{25}	1.4806 − 1.1875 I_{25}	2.3319	3.8125
26	3.8125	1.1875 I_{26}	1.4979 − 1.1875 I_{26}	2.3146	3.8125
27	3.8125	1.1875 I_{27}	1.5126 − 1.1875 I_{27}	2.2999	3.8125
28	3.8125	1.1875 I_{28}	1.5277 − 1.1875 I_{28}	2.2848	3.8125
29	3.8125	1.1875 I_{29}	1.5407 − 1.1875 I_{29}	2.2718	3.8125
30	3.8125	1.1875 I_{30}	1.5548 − 1.1875 I_{30}	2.2577	3.8125
31	3.8125	1.1875 I_{31}	1.5676 − 1.1875 I_{31}	2.2449	3.8125
32	3.8125	1.1875 I_{32}	1.5823 − 1.1875 I_{32}	2.2302	3.8125
33	103.8125	101.1875 I_{33}	135.9861 −101.1875 I_{33}	−32.1736	103.8125

Figure 2: Example of Cash-flow Replication

Some of the pairs had differences in maturity so we had to take account the difference in days. To adjust for the maturity mismatches, we calculated the yield to maturity (YTM) on the synthetic fixed-rate bond formed from the TIPS issue and the inflation swaps, and then used this yield to calculate the price of a synthetic bond that would exactly match the maturity of the Treasury bond in the pair.

The table in Fig.2 was generated after applying the arbitrage strategy on December 30th, 2008 to replicate the 7.625% coupon Treasury bond maturing on February 15, 2025 with 2.375% TIPS issue with same maturity.

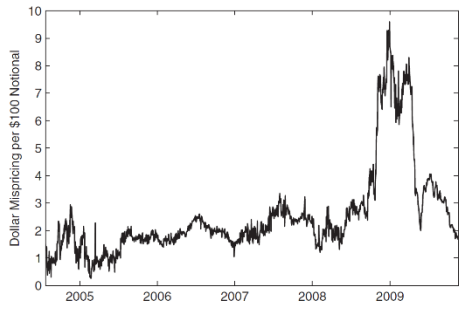
4.3 Summary Statistics for TIPS-Treasury Mispricing

We ran the procedure for 12 pairs and obtained the following results as shown in Fig. 3. The results closely follow the values that were presented in the paper.

Maturity Treasury	Treasury	Maturity Tips	Tips	Mean from Paper	Mean from Code	SD from Paper	SD from Code
12/31/2006	3	1/15/2007	3.375	0.18	0.173436	0.39	0.361457
4/15/2010	4	4/15/2010	0.875	1.09	1.093788	0.65	0.581575
1/15/2011	4.25	1/15/2011	3.500	1.32	1.359952	0.71	0.706759
4/15/2012	1.375	4/15/2012	2.000	1.42	1.371418	0.41	0.374470
7/15/2012	1.5	7/15/2012	3.000	1.66	1.576813	0.37	0.328114
3/31/2013	2.5	4/15/2013	0.625	2.19	2.193086	1.18	1.159827
6/30/2013	3.375	7/15/2013	1.875	4.02	3.988590	1.83	1.856311
12/31/2013	1.5	1/15/2014	2.000	4.38	4.395854	1.5	1.563625
2/15/2025	7.625	1/15/2025	2.375	4.27	4.831810	3.57	3.450301
2/15/2026	6	1/15/2026	2.000	4.9	5.423325	3.16	2.953091
2/15/2027	6.625	1/15/2027	2.375	5.30	5.918375	3.46	3.222212
2/15/2029	5.25	1/15/2029	2.500	6.84	7.730278	3.49	3.294862

Figure 3: Summary Statistics for TIPS-Treasury mispricing for 12 pairs

4.4 Replicating the Arbitrage (2004-2009)



TIPS-Treasury mispricing. This figure plots the time series of the weighted-average TIPS-Treasury mispricing, expressed in units of dollars per $100 notional, across the pairs included in the sample, where the average is weighted by the notional amount of the TIPS issue.

Figure 4: Original Plot of Average Arbitrage from the Paper

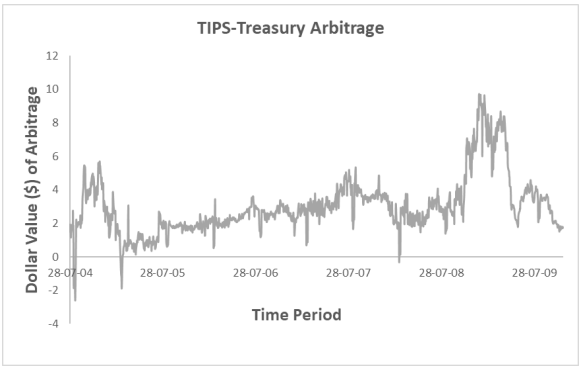


Figure 5: Replication of Average Arbitrage from our Analysis

Figures 4 and 5 show the average arbitrage pricing over the period under consideration. The mispricing amount peaked at $9.60 around the time of the Lehman bankruptcy in the fall of 2008. The overall average

size of the mispricing is $2.92. There were minute differences between our results and those of the paper which can be attributed to a difference in sample size of the pairs.

4.5 Extending the Arbitrage Strategy (2009-2017)

The persistent arbitrage over such a prolonged period is surprising. To check if this was magnified due the recession of 2008, we decided to check if this trend continued in the period from 2009 to 2017. We used 4 pairs of TIPS-Treasury and observed that the arbitrage is disappearing as shown in Fig. 6. We also observe some negative values which might indicate that either the true arbitrage on those days were truly negative. There is also the possibility that we might get smoother curve when we add few more pairs to the consideration.

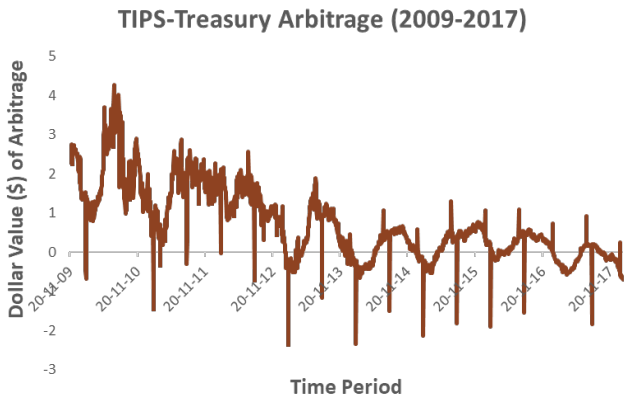


Figure 6: TIPS-Treasury Arbitrage (2009-2017)

5. Regression Analysis

In the previous sections, we have shown that an arbitrage exists between TIPS and Treasury bonds. We will now try to understand the reasons for the mispricing by identifying the factors that may drive the mispricing.

5.1 Regression Factors

- **TIPS Issuance and Treasury Issuance**

The supply of Treasury securities available in the financial markets may be a key factor affecting the ability of arbitrageurs to exploit pricing differences between the TIPS and Treasury bond markets. In particular, it may be easier to execute arbitrage strategies in a market when there is an increase in the supply of on-the-run or recently auctioned bonds.

To explore the effects of supply on TIPS-Treasury mispricing, we include the total notional amount of all TIPS and all Treasury bonds auctioned each month during the sample period. TIPS Issuance denotes the total notional amount of TIPS (in $billions) issued during the month. Treasury Issuance denotes the total notional amount of Treasury notes and bonds (in $billions) issued during the month.

- ### Swap Spread (Credit Risk in the Market)

Another possibility may be that the market perceives the credit risk of TIPS as being slightly higher than that of Treasury bonds. In this case, TIPS might appear to be underpriced relative to Treasury bonds. On the other hand, even if the market viewed the credit risk of TIPS and Treasury bonds as equivalent, changes in aggregate credit risk in other markets might influence their relative pricing. This is because TIPS and Treasury bonds might not be viewed as equally attractive safe havens in the event of a credit-induced flight to quality in the financial markets. To explore the effects of credit risk on TIPS-Treasury mispricing, we use the 10-year swap spread. Swap spreads are one of the most important indicators of the credit risk of the banking system, and have been widely used as measures of aggregate credit risk.

- ### Hedge Fund Returns

To explore the implications of the slow-moving-capital, we examine whether TIPS- Treasury mispricing is affected by a measure of the amount of capital available in the market that could potentially be directed toward arbitrage mispricing.

The ideal data would have been the net asset value of the hedge fund, however since this is proprietary data we were unable to get access to it. To work around this, we decided to look into hedge fund returns index instead. The assumption is that a percentage of hedge fund returns are due to exploitation of TIPS and Treasury arbitrage and, hence, arbitrage could be correlated with the returns.

5.2 Regression Results

The results in Fig. 7. indicate that the mispricing is affected by the supply of new Treasury securities. In particular, the notional amounts of both TIPS and Treasury issuance are statistically significant (at the 10% level). Surprisingly, both regression coefficients are negative in sign. Thus, TIPS-Treasury mispricing decreases in magnitude whenever the Treasury issues TIPS or Treasury bonds.

Explanatory Variable	T-Statistic from paper	T-Statistic - Our work
TIPS Issuance	-1.85	-4.67
Treasury Issuance	-1.71	-2.55
Swap Spread	0.99	1.25
Hedge Fund Returns	-2.32	-1.65
Adjusted R_square	0.175	0.145

Figure 7: Regression Output 2004- 2009

We also see that the systemic credit risk, as measured by the 10-year swap spread, is not significantly related to the TIPS-Treasury mispricing. Strong direct support for the implications of the slow-moving-capital hypothesis.

Explanatory Variable	T-Statistic - Our work
TIPS Issuance	-3.59
Treasury Issuance	-1.98
Swap Spread	0.84
Hedge Fund Returns	-1.82
Adjusted R_square	0.08

Figure 8: Regression Output 2009- 2013

For the period post 2009, we observe in Fig. 8 that the regression results indicate diminishing dependence on the variables. However, the trend does not change for any variable.

6. Mispricing or Liquidity Risk Premium

Mispricing between the synthetic Treasury bonds and the nominal Treasury bonds, at first sight, appears to be a contradiction to the Law of One Price. On the other hand, Drissen, Nijman and Simon claim in their paper 'The Missing Piece of the Puzzle' that the price difference is explained entirely by the liquidity risk premium.

As a matter of fact, the TIPS surplus yield can be broken down into two pieces: inflation risk premium and liquidity risk premium. The first one is what makes TIPS attractive for investors, whereas the latter one is

the negative part; TIPS are less liquid than treasury bonds which pushes their yield higher and thus their price lower.

We aimed to investigate the matter further and determine whether TIPS are beneficial to the Treasury, or, if they are too costly. Fleckenstein, Longstaff, and Lustig claim that "the Treasury could have reduced the cost of the public debt by issuing only nominal bonds" and that due to mispricing, the Treasury unnecessarily increased its debt and lost tens of billions worth of dollars.

$$inflation\ adjusted\ risk\ premium = inflation\ risk\ premium - liquidity\ risk\ premium$$

If the the inflation adjusted risk premium is positive, then the 'good' of TIPS outweighs the 'bad' and hence it is beneficial for the Treasury to continue issuing TIPS. Whereas, if it is negative, then the issuance should be discontinued. (Christenen & Gillan, 2011)

The data we use are nominal and real US Treasury yields observed for 5 and 10 years over the period from 2005 to 2011 to compute the inflation risk premium. We estimate the liquidity risk premium as the average of mispricing. The inflation adjusted risk premium obtained is positive more than 50% of the time, dropping during the crisis of 2008-2009 which is expected but remaining positive during the remaining periods. In addition, the average of the inflation adjusted risk premium is positive. We therefore conclude that the benefits outweigh the disadvantages in TIPS and the issuing these debt securities is beneficial to the Treasury.

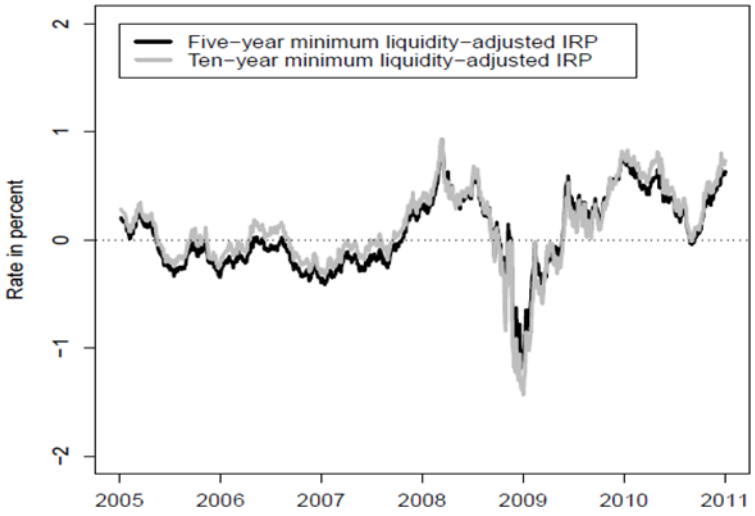


Figure 9: Minimum Liquidity-Adjusted Inflation Risk Premiums (Christensen & Gillan, 2012) (Christenen & Gillan, 2011)

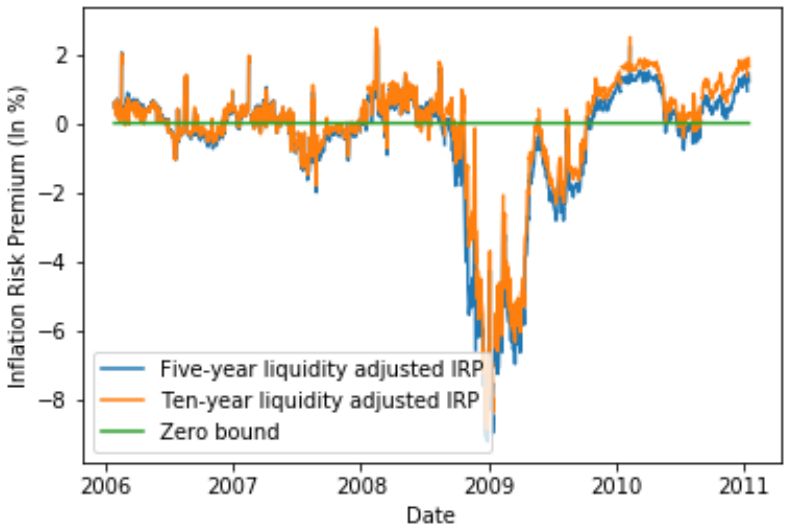


Figure 10: Replication - Inflation Adjusted Risk Premium computed

7. Conclusion

From the above analysis, we conclude that there is a persistent mispricing which has been observed in the past and that existed during the financial crisis. However, we found that the mispricing gradually subsided after the crisis. This trend can be explained by the 'Slow Moving Capital Theory' and the 'TIPS and Treasury Issuance'.

We also found that TIPS are beneficial both for the economy and for the Treasury. As a matter of fact, the positive liquidity-risk-adjusted expected inflation risk premium makes a strong case for the issuance of TIPS showing that their benefits outweigh the costs for the Treasury. In addition, their costs in comparison to bonds is diminishing with the decrease in mispricing values in modern times.

8. Works Cited

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